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Participatory Variety Selection: Increasing Rice Varietal Diversity

Sangay Tshewang[1] and Mahesh Ghimiray[1*]

ABSTRACT

In order to broaden the genetic base of rice crop, two released and four pre-released varieties were evaluated through Participatory Variety Selection (PVS) program in a remote village in west central Bhutan. After field evaluation for three years, farmers have adopted one released and one pre-released variety thereby increasing the rice varietal diversity to four. Now 80% of the farmers cultivate new varieties selected through PVS along with their local variety; the remaining farmers could not adopt due to shortage of land and farm labour. Farmers have a number of criteria for selecting new rive varieties and these traits vary among communities and individual farmers. PVS has the potential of becoming one of best approaches in research and extension especially in remote areas that are resource poor and have limited number of crop varieties.

***KEYWORDS*:** PVS, improved varieties, local varieties, diversity.

INTRODUCTION

Maintenance of biodiversity is considered as one of the fundamentals to agricultural production and food security and an essential component of environmental conservation (Thrupp 2000). Joshi and Sthapit (1990) regarded varietal diversity as an important ingredient in agriculture system as it addresses the varied needs of the physical environments, socio-economic conditions and needs of the farmers. It is however ironical to note that landraces in many crops have been identified as the most threatened category of genetic resources (Fowler and Mooney, 1990 in Brush and Meng 1998) due to expansion of agricultural production in frontier areas.

[1] Renewable Natural Resources Research and Development Centre, Bajo, Wangduephodrang

*****Corresponding author: mghimiray@gmail.com

Several research and extension approaches have evolved in evaluating and disseminating the tested technologies to the farming communities. One of the approaches has been the conventional method which involves considerable time and cost thereby resulting into selection of few adapted varieties (Joshi *et al*. 1997). The conventional system also restricts farmers' participation in technology development despite their wealth of knowledge and skills in selecting crops and varieties that can suit their needs, fit in local environments and fulfill consumer satisfaction.

An alternative approach has been the PVS which employs an intensive system of farmer managed participatory research (FAMPAR) (Joshi and Witcombe 2002). This system facilitates farmers to take active participation in selecting breeding lines (Joshi *et al*. 1997) or the finished varieties (Rice *et al*. 1998). Their early participation favours farmers to select varieties according to their preferences, needs and other expected characteristics. Such system has been successfully tested in rice (Dorward *et al*. 2007; Joshi and Witcombe 2002), sorghum (Mulatu and Belete 2001), maize (Mulatu and Zelleke 2002) and potato (Thiele *et al*. 1997) and has led to increased adoption rates by farmers.

Rice (*Oryza sativa* L.) is the most important cereal in Bhutan. Although it is not the largest produced cereal in the country, it is the most widely consumed cereal (Ghimiray *et al.* 2006). Rice feeds majority of the Bhutanese population as a staple food (RNRRC Bajo 2008). In this study, we tried to assess the increase in on-farm diversity of rice varieties after implementing PVS as part of the Biodiversity Use and Conservation in Asia Program (BUCAP) project in a remote village, Samthang, in west central Bhutan.

MATERIALS AND METHODS

Site Description

Samthang is one of the remotest villages in Adang Geog of Wangduephodrang Dzongkhag. It is located at an altitude of 850 masl. The village has both wetland and dryland in varying acreage. Soils are blackish, light and sandy with moderate fertility levels (RNRRC Bajo 2005) and the village experiences a very hot summer and mild winter. Rice is an important food crop though other crops such as maize, wheat and mustard are also cultivated. The village is yet to be connected with a

motorable road and electricity, however, a primary school has recently been established.

The community had a narrow genetic base of most food crops including rice and is prone to loss of biodiversity. Only two varieties of rice were cultivated by farmers (RNRRC Bajo, 2005). A preliminary assessment of the agriculture production system in Samthang conducted by RNR RC Bajo strongly recommended a program such as BUCAP to broaden the genetic base of important food crops in the community, particularly rice and maize, and enhance the technical capacity of farmers to be able to maintain diverse varieties.

Varietal Selection

Since the site is located in the mid altitude region, the released and promising varieties for mid altitude were provided to the farmers (Table 1). All the released and pre-released materials were introductions from the International Rice Research Institute (IRRI), Philippines that have been tested under Bhutanese agro-ecological conditions. In the PVS at Samthang only released and pre released varieties were included to reduce the risks of crop failure and to win the farmers support through a successful demonstration as the program was implemented for the first time.

Further sufficient quantity of seeds of released and pre released varieties is be available if they perform well and there is a demand from the farmers.

Table 1: Rice varieties included in the PVS trial

Variety name	Year of release	Recommended Alt.	Remarks
IR 64	1988	800-1500 masl	Improved released variety
Bajo Kaap 2	1999	800-1500 masl	Improved released variety
B2983B-SR-85-3-2-4	-	800-1500 masl	Pre released
IR 62467-B-R-B-F8-1-B	-	800-1500 masl	Pre released
IR 62467-B-R-B-B-1-1-B	-	800-1500 masl	Pre released
IR 62467-B-R-B-4-1	-	800-1500 masl	Pre released
Attey	-		Local variety

Source: Ghimiray *et al*. 2001

PVS Trials

To avoid the loss of confidence by farmers in case of failure, PVS trial in the first year was implemented in a common working plot (so called mother trial) that was provided by an interested farmer. In the subsequent years, the varieties selected from the first year trial were grown by farmers in their respective farms (so called baby trial). All the farmers participated in the crop cultivation operations and the entire trial was managed by them from nursery sowing till harvesting. Technical advice about the requirement of the newly introduced varieties with particular emphasis on nursery and nutrient management was given by the researchers. Adjacent to the test varieties were farmers' own local varieties for comparison purposes.

During the critical crop growth stages such as tillering, flowering and maturity, a joint field visit called 'farm walk' was organized (Joshi and Witcombe 2002) which was participated by farmers, researchers and extension personnel. Such visits were beneficial for participating farmers in comparing the varieties when they are in the field and an opportunity for research and extension personnel to point out the differences. A field day at the harvest time was more important in assessing the yield potential and other yield contributing parameters.

Monitoring the Adoption of Improved Varieties

After the program initiation, field visits were made regularly to monitor the activities and backstop the farmers technically. Varietal adoption and preferences were recorded during field visits. After 3 years (2005-2007) of program implementation, an impact assessment survey was carried out in 2008. This survey assessed the number of farmers adopting the new rice varieties, different rice varieties cultivated by the farmers, reason for adoption and yield of the different varieties.

RESULTS

Adoption of Rice Varieties

Two released varieties and four pre-released lines were tested in the PVS along with a local check (Table 2). After 3 years of the program implementation, farmers adopted one released and one pre-released variety. Among the released varieties, farmers selected IR 64 while from the pre-released group, B2983B-SR-85-3-2-4 was preferred. IR 64 was adopted by 22% of the farmers and B2983B-SR-85-3-2-4 by 55%.

Farmers Perception on new rice varieties

Farmers said that the all the new rice varieties selected from PVS produced higher yield as compared to their local variety (Table 2). They said that the new varieties were responsive to inorganic fertilizers such as urea and resistant to lodging. The negative traits of the new varieties included shorter plant height and less straw. Straw yield is an important byproduct for farmers to feed their cattle. Farmers agreed that their local varieties were poor yielders and susceptible to lodging. The traditional varieties were also not responsive to nitrogenous fertilization.

Table 2: Yield of tested varieties averaged over three seasons/years

Variety name	Yield (t/ha)	Remarks
IR 64	4.80	Improved released variety
Bajo Kaap 2	4.30	Improved released variety
B2983B-SR-85-3-2-4	5.15	Pre released variety
IR 62467-B-R-B-F8-1-B	2.59	Pre released variety
IR 62467-B-R-B-B-1-1-B	3.17	Pre released variety
IR 62467-B-R-B-4-1	3.33	Pre released variety
Attey	2.80	Local variety

Increase in varietal diversity

Before the project intervention, there were only two rice varieties indicating a narrow genetic base. Farmers did not have any choice of variety as they did not have access to information or seeds of new genetic materials. After the PVS program, farmers selected two more varieties increasing the number of rice varieties in the village to four (Figure 1). Rice varietal diversity and choice for farmers has thus double.

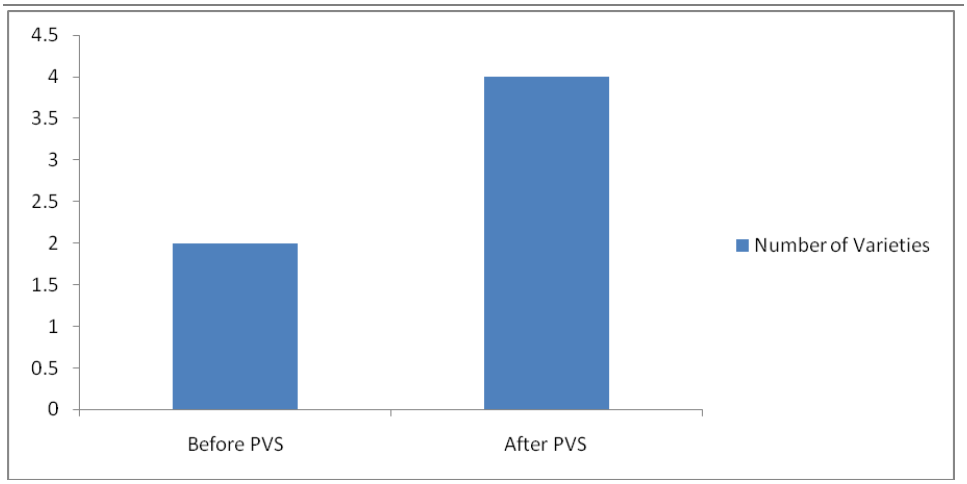

Figure 1: Varietal diversity before and after the PVS

DISCUSSION

An increase in varietal diversity of rice has been achieved through the PVS program. Farmers in the project site could identify high yielding rice varieties that were well adapted to their local agro-ecological conditions and suit their needs, both socially and economically. Just like in the formal system of considering yield as the major deciding criterion (Joshi *et al.* 1997), majority of farmers looked at the yield potential while selecting the new varieties. However, yield was not the sole determinant for selection as 22% of farmers did not adopt any of the improved varieties. Socio-economic conditions of the farmers also affect PVS adoption (Joshi *et al.* 1997) and the farmers in the present study site had small landholdings and scarcity of family labour. Further, factors such as production stability, performance in different agro-climatic zones, fit to household schedules may also contribute to selection of local varieties instead of or along with the modern varieties (Brush and Meng 1998).

Apart from yield potential, other qualitative and agronomic characteristics also influence varietal adoption. For example in Nepal, Joshi *et al.* (1997) reported that even if the varieties were high yielders, farmers reject them if they possess poor cooking quality, low milling recovery, short height, poor taste and difficulty in threshing. Our study also noted a similar behavior of the farmers. The IR62467 lines, despite being high yielders except one (Table 2), were rejected in the first year because they were early maturing and were susceptible to attacks by birds and rodents. Farmers also complained of the difficulty to thresh the these lines manually as it demanded more labour and time.

It is generally perceived that adoption of improved varieties will lead to abandonment of land races. Thrupp (2000) reported that introduction of high yielding improved varieties have displaced more than 300 local varieties in the Philippines. However, Brush (1995) with a serries of field research in different farming systems found diffusion of improved varieties to be complex and rate and extent of replacement of land races by modern varieties to be context specific. Further, it was argued by Brush and Meng (1998) that adoption of improved varieties does not necessarily eliminate local varieties but the area under its cultivation is decreased as certain portion of land would have been occupied by the introduced varieties. Our study concurred with the latter authors as farmers still continue to grow their traditional varieties in addition to the varieties selected from PVS. Farmers who have adopted new varieties still dedicate some portion of their land for local varieties.

The diffusion of seeds of improved varieties between farmers was not prominent in the present study. This could be due to the fact that all the farmers in the community were participants and had received seeds initially. Joshi and Witcombe (2002) also noted low farmer to farmer seed dissemination under farmer managed participatory research because farmers under such PVS system felt that project would resupply the seed if needed. In contrast, Dorward *et al*. (2007) reported widespread distribution of PVS selected rice varieties from village to village by more than 100 km through informal channels. In our study, it was disheartening to note that two neighbouring villages (non-project areas) despite lying approximately 25 km away from the project site have not availed any PVS varieties through seed exchange or purchase despite having similar agro-ecological conditions.

PVS needs to be a continuous and sustainable program and hence PVS programs should be low cost and handled by the farmers themselves or local organizations (Dorward *et al*. 2007). Thus, building of technical capacity of farmers needs to be institutionalized at the beginning of the PVS program. Though not reported here, seed selection training, improved methods of rice cultivation and other recommended technologies were imparted to the PVS farmers. Research and extension will continue periodic monitoring and receive farmers' feedbacks on the new varieties.

PVS programs are likely to yield the largest impacts where no varieties have been introduced for many years (Dorward *et al*. 2007). Further, PVS succeeds mainly in marginal areas with resource poor farmers and limited number of land races (Belay *et al.* 2005). Our PVS program was also implemented in one of the remotest villages where farmers lacked access to improved varieties before. Bhutanese rice farmers are generally poor with small land holdings and are isolated owing to difficult terrain and lack of road access. PVS thus can prove to be an effective research and extension methodology in testing and promoting new and improved varieties in remote areas to realize the goal of food self sufficiency and food security in the country.

CONCLUSION

PVS has proven to be successful in field evaluation of the finished or preleased varieties leading to increase in on-farm varietal diversity. The increase in production was also realized with the adoption of high yielding varieties. However, equally important is the indigenous knowledge of farmers in field evaluation and identification of specific traits that farmers look for in new varieties. Such an approach will have greater impact in future breeding programs or introduction of varieties from elsewhere.

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Identification of Accelerated Aging Conditions for Seed Vigor Test in Rice (*Oryza sativa* L.)

Suraj Chhetri[1] and Thawatchai Teekachunhatean[2]

ABSTRACT

The accelerated aging conditions commonly practiced in Thailand as seed vigor test in rice is not accurate and no recommended accelerated aging test conditions for rice seed is prescribed in international seed vigor testing handbooks. The main objective of this study was to investigate accurate combinations of temperature and time for the accelerated aging conditions for seed vigor test in rice. The minor objective was to explore for efficient vigor tests for rice seeds other than accelerated aging test. Twenty four rice seed lots of 3 common Thai varieties (Chai Nat1, Khao Dok Mali 105 and Phitsanulok1) of different vigor levels from different seed centers and research centers in Thailand were used in the experiment. The following tests were conducted: standard germination, field emergence, seedling root length, seedling shoot length, total seedling length, seedling growth rate, conductivity and accelerated aging at 42, 43 and 44 ^{o}C for 72, 96 and 120 hrs at each temperature. In the multiple correlation analyses, all tests showed highly significant correlations ($p < 0.01$) with field emergence ($r = 0.55^{**}$ to 0.82^{**}). The three single vigor test that provided highest correlation with field emergence were conductivity test ($r = -0.82^{**}$), accelerated aging test at 44 ^{o}C for 72 hrs ($r = 0.78^{**}$) and seedling shoot length ($r = 0.75^{**}$), respectively. Among conductivity test and 9 accelerated aging conditions the highest correlation ($r = -0.71^{**}$) was observed between conductivity and accelerated aging at 44 ^{o}C for 72 hrs. Based on the result obtained it can be concluded that the accelerated aging condition at 44 ^{o}C for 72 hrs and conductivity test should be generally recommended for vigor test in rice seeds of Thai varieties.

KEY WORDS: rice seeds, seed vigor tests, accelerated aging test, conductivity test.

[1]Druk Seed Corporation, MoA, Paro

[2]Asst. Professor, School of Crop Production Technology, Institute of Agricultural Technology, Suranaree University of Technology, Nakhon Ratchasima, Thailand.

INTRODUCTION

Accelerated aging test is a stress test. Seeds are placed in temperature of 40-45 °C and nearly 100 % relative humidity for varying lengths of time, depending on the kinds of seeds, after which a germination test is made. The basis for this test is that higher vigor seeds tolerate the high temperature-high humidity treatment and thus retain their capability to produce normal seedlings in the germination test (AOSA, 1983). Accelerated aging test is a very popular seed vigor test in seed testing laboratories as it is rapid, simple, no sophisticated equipment are needed and it could be done by any seed analyst with minimal training. Surveys of seed testing laboratories in North America have shown that accelerated aging test is one of the most frequently used vigor tests (AOSA, 1983). The accelerated aging method has been proven as indicator of seed vigor in wide range of crop species and has been successfully related to field emergence and stand establishment, for example in seeds of wheat (Tomer and Maguire, 1990), corn (Santipracha et al., 1997), soybean (Egli and Tekrony, 1995) and watermelon (Mavi and Demir, 2007). Besides, seed vigor test for predicting field emergence, it can also be used in evaluating storage potential of crop seeds (Delouche and Baskin, 1973).

All rice seed centers in Thailand also use accelerated aging as seed vigor test in rice but there is no standard accelerated aging conditions among rice seed centers, and the aging conditions they adopt in the laboratory test do not separate vigor levels of seed lots, thus affecting the accuracy of seed vigor estimation which seedspersons use to make decision for seed storage duration and arrangement for sale release priority. Determination of seed vigor in rice seeds seems to be more important recently because some recommended varieties of rice tend to have low seed vigor. Germination percentages of those varieties usually decrease immediately after ripening period [Singkanipa, 2008 (personal communication)].

However, few researches have been conducted in accelerated aging as rice seed vigor test and currently there is no suggested or recommended accelerated aging test conditions available in seed vigor testing handbook from the International Seed Testing Association (ISTA, 1995) or the Association of Official Seed Analysts (AOSA, 1983). The major objective of the present study was to develop a proper testing condition of temperature and period for accelerated aging as rice seed vigor test for

common Thai varieties and the minor objective was to survey for possibility alternative rice seed vigor tests other than accelerated aging test.

MATERIALS AND METHODS

The experiment was carried out from July 2008 to March 2009 at Seed Technology Laboratory, Suranaree University of Technology, Nakhon Ratchasima Province, Thailand. Completely Randomized Design of 24 seed lots with 3 replications were used in the experiment. The rice varieties used were 1) Kao Dok Mali 105 (KDML105), 2) Chai Nat1 (CNT1) and 3) Phitsanulok1 (PSL1). Each variety consisted of 8 seed lots with different vigor levels ranging from 40-80 % as determined by field emergence test. The following tests were conducted: standard germination, field emergence, seedling root length, seedling shoot length, total seedling length, seedling growth rate, conductivity and accelerated aging at 42, 43 and 44 ^{o}C for 72, 96 and 120 hrs at each temperature.

Seed procurement

Fifty four seed lots of different rice varieties were procured from various rice seed centers and rice research centers in Thailand. The seed moisture content measured by electrical moisture meter (lab model Steinlite SB900, Seedburo Equipment Company, USA) ranged from 10-12 %. Seed lots were packed in sealed plastic bags and stored in cold storage at 5 °C and 60 % R.H. until used in the experiments. A preliminary field emergence test was conducted and accordingly 24 seed lots of 3 rice varieties of different vigor level ranging from 40-80 % of field emergence were selected for the experiment**.**

Seed testing procedures

a. Standard germination test (SG)

Three replications of 50 seeds were germinated between germination paper towels (BP) at 25 ^{o}C and 8 hrs light in the germinator. Seedling evaluation were done at 5 and 10 days after incubation following the procedure for standard germination test as described in the ISTA rules for seed testing (ISTA, 1999).

b. Field emergence test (FE)

Three replications of 50 seeds were hand planted (50 seeds per row) in concrete plots (19.0 m x 0.80 m) in plastic roofed house. The soil was

sandy clay loam. The plots were watered immediately after planting the seeds through plastic hose and every day thereafter. Healthy seedlings were counted at 15 days after sowing.

c. Seedling root length (RL)

Three replications of 25 seeds were germinated between germination paper towels at 25 ^{o}C in 45 º upright position in the dark germinator. The seedling root lengths of only normal seedlings were measured in cm at 7 days after planting and means of seedling root length were calculated in cm per seedling (ISTA, 1995).

d. Seedling shoot length (SL)

The same samples used in the determination of seedling root lengths as described in c were used to measure seedling shoot lengths. Only normal seedlings were measured for seedling shoot lengths in cm. Means of seedling shoot length then were calculated in cm per seedling**.**

e. Total seedling length (TL)

Mean of total seedling length of each seed lot was determined by the accumulation of seedling root and shoot length means of each seedling as demonstrated in c and d, respectively.

f. Seedling growth rate test (SGR)

Three replications of 25 seeds were germinated between papers at 25 ^{o}C in 45 º upright position in the dark germinator. After 7 days only normal seedlings were cut free from seeds and oven dried at 80 ^{o}C for 24 hrs and weighed in gram. Seedling dry weights in gram per seedling were calculated as described by ISTA seed vigor testing handbook (ISTA, 1995).

g. Conductivity test (CT)

Three replications of 25 uninjured seeds were weighed to 2 decimal places and placed in 200 ml beaker with 75 ml of deionized water. The beakers were placed at the constant temperature of 20 °C for 24 hrs. The conductivity of leachates was measured by using conductivity meter (model Consort C831, Cole-Parmer Instrument Company, Belgium) and conductivity per gram of seed weight was calculated (µS $cm^{-1}g^{-1}$) and recorded as per the AOSA seed vigor testing handbook (AOSA, 1983).

h. Accelerated aging test (AA)

Three replications of 50 seeds of each seed lots were placed one layer deep in wire mesh baskets (8 cm in diameter and 5.5 cm in height excluding legs which are 3.5 cm long). One hundred and twenty ml of water was then added to the plastic box (10 cm in diameter and 10.5 cm in height). To prevent the dropping of condensed vapor from the lid into the seeds, one piece of blotter paper of circular shape was placed on each basket. The lid of the plastic box was then tightly closed and placed into incubator at the required temperature and hours. Subsequent to aging the seeds were germinated as the procedure described in a, the standard germination test.

Statistical analysis

Analyses of variances were performed on the data with the Statistical Package for Social Sciences (SPSS) version 15. Duncan's multiple range test (DMRT) was used in the mean comparison. Correlation coefficients between all test results were calculated to observe the relationships of all tests.

RESULT AND DISCUSSION

The germination percentages of 24 seed lots ranged from 44 to 99.33 % and highly significant differences were observed among means of 24 seed lots (table 2). When the seeds were planted in the field, field emergence showed significant difference ($p < 0.05$) between means of seed lots. The results of 5 seed vigor tests; seedling root length, seedling shoot length, total seedling length, seedling growth rate and conductivity test showed very highly significant differences among its seed lot means except seedling growth rate test which was non-significant. Each accelerated aging condition also showed highly significant difference among 24 seed lots (table 1).

Highly significant correlation ($r = 0.64^{**}$) was observed between standard germination test and field emergence (table 2). All seed vigor tests; seedling root length ($r = 0.56^{**}$), seedling shoot length ($r = 0.75^{**}$), total seedling length ($r = 0.63^{**}$), seedling growth rate test ($r = 0.54^{**}$) and conductivity test ($r = -0.82^{**}$) provided highly significant correlations with field emergence. Correlations of 9 accelerated conditions with field emergence also were highly significant ($r = 0.55^{**}$ to 0.78^{**}) (table 2).

Among all tests, the three highest correlations with field emergence were conductivity test (r = -0.82**) followed by accelerated aging condition at 44 ºC for 72 hrs (r = 0.78**) and seedling shoot length (r = 0.75**), respectively. According to conductivity test, seedling shoot length showed highest correlation (r = -0.82**) followed by accelerated aging condition at 44 ºC for 72 hrs (r = -0.71**) (table 2). From the above findings the accelerated aging condition at 44 ºC for 72 hrs and conductivity test are recommended for rice seed vigor test in Thai rice varieties. Seedling shoot length seems to be a good rice vigor test, but it may not be applicable in seed laboratories, as it is time consuming and tedious.

Very few researches are available in accelerated aging as rice seed vigor test. Bradford (1988) evaluated rice seed lots through accelerated aging test and observed that accelerated aging test could provide additional useful information about seedling vigor and seed germination of 40% or higher after accelerated aging test correlated well with field emergence. Patin and Gutormson (2009) at Mid-West Seed Services. Inc. South Dakota, USA, studied various seed vigor test in 10 rice samples and suggested that cold test and accelerated aging test could be suitable seed vigor tests in rice and should be verified with actual field emergence. Chea

(2006) performed tests on 2 rice varieties (KDML105 and RD6) to find possible seed vigor tests which could predict field emergence and suggested that standard germination test, accelerated aging test (41^{o}C, 84 hrs), seedling growth rate and conductivity test could be used in predicting field emergence in rice seeds. The above suggestions support our finding that accelerated aging test could be used as an accurate seed vigor test in rice.

Table 1: Standard germination and vigor tests of 24 seed lots of 3 rice varieties, data sorted according to varieties and minimum to maximum percentages of standard germination test

Cultivar	Lots	SG (%)	FE (%)	RL (cm)	SL (cm)	TL (cm)	SGR (mg/plant)	CT ($\mu S\ cm^{-1}g^{-1}$)	Accelerated Aging Condition								
									42 °C 72 hrs (%)	42 °C 96 hrs (%)	42 °C 120 hrs (%)	43 °C 72 hrs (%)	43 °C 96 hrs (%)	43 °C 120 hrs (%)	44 °C 72 hrs (%)	44 °C 96 hrs (%)	44 °C 120 hrs (%)
CNT1	36	44.00 h	31.33e	2.84h	0.79g	3.63i	0.160	81.98a	13.33g	1.33k	0.00f	29.33e	11.33g	4.00d	0.00i	0.00f	0.00h
CNT1	72	80.67g	48.67c-e	8.49g	3.67e-f	12.16g-h	4.467	31.36d-g	73.33a-e	65.33b-e	42.00a-d	79.33a-c	77.33a-c	33.33b-c	27.33g-h	4.67e-f	2.00g-h
CNT1	34	82.00f-g	66.00a-e	9.29f-g	3.95a-f	13.23f-h	4.125	28.25e-g	44.67f	41.33g-j	20.67c-e	50.00d	58.00c-f	58.67a-c	56.67b-g	38.00a-d	19.33b-f
CNT1	71	83.33 e-g	61.33a-e	8.53g	3.36f	11.89h	3.096	33.34d-e	73.33a-e	57.33c-g	28.67b-e	86.67a-b	72.66a-d	54.66a-c	35.00f-h	12.67de	1.33g-h
CNT1	85	90.67 b-e	79.33a-c	9.62f-g	4.31a-f	13.93e-h	5.436	27.76e-g	90.00a-b	57.33c-g	45.33a-d	86.00a-b	80.67a-c	81.33a	78.00a-b	32.67a-d	20.67b-f
CNT1	54	93.33 a-d	76.00a-d	11.19d-f	4.44a-e	15.64c-f	5.257	26.76e-g	78.00a-d	73.33a-c	70.00a	85.33a-b	86.67a-b	48.00a-c	79.33a-b	70.00a	45.33a-b
CNT1	8	94.00 a-d	85.33a-b	10.65d-g	4.44a-e	15.09c-g	5.004	23.57g	81.33a-c	51.33c-g	48.00a-c	90.67a-b	66.00a-f	64.00a-c	59.00b-f	32.67b-d	6.00d-h
CNT1	24	94.67 a-d	86.67a	11.02d-f	4.78a-d	15.81b-f	4.430	23.12g	84.00a-b	82.00a-b	53.33a-b	90.67a-b	90.00a	84.00a	95.33a	65.33a-b	62.00a
KDML	48	88.67 c-g	42.00d-e	10.94d-f	3.60e-f	14.54d-h	3.246	34.15d-e	62.67d-e	31.33j	22.00c-e	71.33b-c	47.33d-f	28.00c	21.33h-i	13.33d-f	4.00d-h
KDML	46	88.67 c-g	65.33a-e	10.79d-f	4.09c-f	14.88c-h	5.166	32.97d-f	85.33a-b	48.00e-j	28.00b-e	79.33a-c	43.33e-f	36.67a-c	52.00 b-g	34.67a-d	22.67b-d
KDML	90	89.33 c-f	49.33b-e	10.24e-g	3.92d-f	14.16e-h	4.908	35.15d-e	79.33a-d	50.67d-i	21.33c-e	80.00a-c	74.67a-d	63.33a-c	42.00d-h	22.00c-e	0.00h
KDML	5	90.67 b-e	72.00a-d	11.99b-e	4.43a-e	16.42b-e	5.759	24.56f-g	65.33c-e	35.33h-j	28.00b-e	64.67c-d	58.00c-f	60.00a-c	67.33a-e	38.67a-d	26.00b-c
KDML	82	94.67a-d	76.67a-d	12.80a-d	4.95a-c	17.75a-c	6.582	27.54e-g	86.67a-b	57.33c-g	32.00b-e	92.00a	78.00a-c	79.33a	76.67a-c	59.33a-c	40.67a-b
KDML	106	96.00a-c	54.67a-e	12.38a-e	4.94a-c	17.32a-d	4.366	44.18b-c	72.00b-e	64.00b-f	54.67a-b	78.67a-c	68.00a-f	56.00a-c	57.33b-f	16.67d-e	14.00b-g
KDML	9	98.67a-b	84.00a-c	14.28a	5.23a	19.51a	4.960	24.87f-g	82.67a-c	68.00a-d	29.33b-e	91.33a	65.33a-f	64.00a-c	60.67b-f	28.00a-d	17.33c-g
KDML	88	99.33 a	80.00a-c	13.55a-c	5.11a-b	18.66a-b	5.933	24.83f-g	90.67a	84.00a	58.00a-b	83.33a-c	88.00a-b	48.00a-c	56.67b-g	6.00 ef	4.00f-h
PSL1	135	83.33 e-g	64.67a-e	11.40c-f	3.65e-f	15.05c-g	6.645	44.10b-c	79.33a-d	62.00c-f	12.00e	77.33a-c	69.33a-e	56.00a-c	39.67e-h	29.33b-d	10.67c-g
PSL1	132	87.33 d-g	60.67a-e	10.34e-g	3.51e-f	13.86e-h	4.920	37.28c-d	80.00a-d	32.00i -j	11.33e	80.00a-c	42.00f	62.00a-c	62.33b-f	15.33d-e	3.33e-h
PSL1	134	88.00 c-g	56.00a-e	13.65a-b	3.75e-f	17.41a-d	6.555	48.04b	74.00a-e	41.33 g-j	38.00a-e	74.67a-c	63.33a-f	64.67a-c	70.67a-d	40.00a-d	3.33d-h
PSL1	131	89.33 c-f	60.00a-e	10.44e-g	3.61e-f	14.06e-h	6.080	38.09c-d	74.67a-e	45.33 f-j	18.00d-e	81.33a-c	74.67a-d	50.00a-c	47.33c-h	33.33a-d	13.33b-g
PSL1	133	91.33 a-e	60.67a-e	11.11d-f	3.72e-f	14.83c-h	4.924	36.80c-d	60.00e	41.33g-j	30.67b-e	64.67c-d	58.00c-f	42.00a-c	58.00b-f	9.33d-f	10.00c-h
PSL1	129	92.67 a-d	57.33a-e	10.33e-g	3.85d-f	14.18e-h	4.539	47.52b	84.00a-b	55.33c-g	26.00b-e	80.00a-c	72.00a-d	55.33a-c	50.00b-h	24.00c-e	6.00c-h

PSL1	130	94.00 a-d	52.00a-e	11.37c-f	4.13b-f	15.51c-f	5.348	35.16d-e	81.33a-c	46.67e-j	30.00b-e	82.67a-c	77.33a-c	72.67a-b	62.67b-f	15.33d-e	8.67c-h
PSL1	128	94.00 a-d	70.00a-d	12.01b-e	4.24a-f	16.25b-f	5.593	33.54d-e	82.00a-c	56.67c-g	39.33a-d	80.00a-c	61.33b-f	45.33a-c	68.00a-e	31.33a-d	20.00b-e
Mean		**88.69**	**64.17**	**10.80**	**4.02**	**14.82**	**4.895**	**35.21**	**74.08**	**52.03**	**32.78**	**77.47**	**65.97**	**54.64**	**55.14**	**28.03**	**15.03**
F test		**	*	**	**	**	**ns**	**	**	**	**	**	**	**	**	**	**
C.V. (%)		**4.87**	**28.25**	**10.74**	**12.9**	**10.66**	**38.70**	**12.48**	**12.2**	**19.2**	**24.57**	**12.6**	**21.16**	**22.22**	**27.98**	**35.55**	**50.77[4]**

[1] = Means in the same column that followed by the same letters are not significantly different according to DMRT.
*, **, ns = Significant difference at $p < 0.05$, $p < 0.01$, and non-significant, respectively.

Table 2: Correlation coefficient (r) of standard germination, field emergence, accelerated aging test of 9 conditions and other seed vigor tests of 24 seed lots of 3 rice varieties

							Accelerated Aging Condition									
Test	**SG**	**RL**	**SL**	**TL**	**SGR**	**CT**	**42 °C 72 hrs**	**42 °C 96 hrs**	**42 °C 120 hrs**	**43 °C 72 hrs**	**43 °C 96 hrs**	**43 °C 120 hrs**	**44 °C 72 hrs**	**44 °C 96 hrs**	**44 °C 120 hrs**	**FE**
SG	1.00	0.88 **	0.93 **	0.92 **	0.73 **	-0.76 **	0.84 **	0.69 **	0.59 **	0.80 **	0.70 **	0.65 **	0.71 **	0.38	0.33	0.64 **
RL		1.00	0.86 **	0.99 **	0.80 **	-0.58 **	0.71 **	0.57 **	0.45 *	0.64 **	0.52 **	0.54 **	0.64 **	0.36	0.26	0.56 **
SL			1.00	0.92 **	0.69 **	-0.82 **	0.77 **	0.77 **	0.66 **	0.74 **	0.71 **	0.67 **	0.74 **	0.46 *	0.47 *	**0.75** **
TL				1.00	0.79 **	-0.66 **	0.75 **	0.64 **	0.53 **	0.69 **	0.59 **	0.60 **	0.69 **	0.40	0.33	0.63 **
SGR					1.00	-0.62 **	0.75 **	0.50 *	0.32	0.61 **	0.59 **	0.61 **	0.65 **	0.45 *	0.26	0.55 **

CT	1.00	-0.68 **	-0.69 **	-0.56 **	-0.68 **	-0.69 **	-0.65 **	**-0.71 ** **	-0.48 *	-0.48 *	**-0.82** **
42 °C /72 hrs		1.00	0.74 **	0.50 *	0.94 **	0.72 **	0.65 **	0.61 **	0.34	0.26	0.61 **
42 °C /96 hrs			1.00	0.74**	0.75 **	0.86 **	0.48 *	0.53 **	0.37	0.44 *	0.66 **
42 °C /120 hrs				1.00	0.54 **	0.68 **	0.32	0.60 **	0.40	0.46 *	0.56 **
43 °C /72 hrs					1.00	0.74 **	0.64 **	0.56 **	0.37	0.30	0.61 **
43 °C /96 hrs						1.00	0.65 **	0.58 **	0.42 *	0.39	0.55 **
43 °C /120 hrs							1.00	0.79 **	0.54 **	0.44 *	0.64 **
44 °C /72 hrs								1.00	0.74 **	0.71 **	**0.78** **
44 °C /96 hrs									1.00	0.86 **	0.62 **
44 °C /120 hrs										1.00	0.63 **
FE											1.00

*,** = significant difference at $p < 0.05$ and $p < 0.01$, respectively.

CONCLUSION

The accelerated aging condition at 44ºC for 72 hrs is generally recommended as seed vigor test in rice for common Thai varieties. Conductivity test is also recommended as alternative test for rice seed vigor test. The seed vigor test in general and accelerated aging test in specific could be used in any of the private or public seed sector in Bhutan. There have been complaints raised by our colleagues in the field that the field emergence percentages are always lower than truthful label of laboratory standard germination percentages. Accelerated aging test could be the solution to such problem. Accelerated aging test could be used as an in house quality control to narrow the gap between standard germination and field emergence percentages.

Currently, there are evidences that specific plant varieties or types need specific accelerated aging conditions for the most accurate vigor test results (Komba et al., 2006; Santipracha et al., 1997). Therefore, determinations of accurate accelerated aging conditions are needed for general and specific Bhutanese rice varieties before adoption of the test. The accelerated aging test has been used to screen out tolerance of different rice varieties to natural aging and adverse environmental conditions (Siddique et al., 1988). The experiment with appropriate aging conditions could be used by plant breeders in Bhutan to screen out rice varieties for aging tolerance which could help in developing improved varieties with the potential for maintaining longer and stronger seed viability in storage.

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Effect of tillage on pupal mortality of the Chinese citrus fruit fly, *Bactrocera minax* (Enderlein) (Diptera:Tephritidae)

Chencho Dorji[1], Kiran Mahat[2] and Phuntsho Loday[3]

ABSTRACT

This study investigated the effect of tillage on pupal mortality of the Chinese citrus fruit fly, Bactrocera minax (Enderlein) (Diptera:Tephritidae) an important pest of mandarin in Bhutan. It also observed the role of natural predation in reducing the over all fruit fly pupal number in the soil.

In a citrus orchard in Punakha, 24 square plots each measuring 0.5m by 0.5m were demarcated with wooden spikes under citrus trees. A total of 30 dropped fruits were introduced in each of these squares. Half of these plots were either covered with wire mesh or left exposed. Out of these plots, 6 exposed plots and 6 covered plots were tilled in mid Janaury. A total of 180 dropped fruits were randomly collected and brought to the laboratory to estimate the pupal number emerging from cohorts of 30 fruits placed in the field plots. In mid March all plots were sieved and total number of pupae present was recorded. The result indicated no significant reduction in the number of B. minax pupae due to tillage. However, a significant difference was observed in the total number of pupae obtained in the laboratory compared to the ones left exposed in the field, indicating a high rate of natural predation of fruit fly pupae in the field.

KEY WORDS: Citrus, Chinese citrus fruit fly, *Bactrocera minax*, Tillage, Natural predation, Control

INTRODUCTION

[1] National Plant Protection Centre, MoAF (Until- 2008;now Ministry of Education)
[2] National Plant Protection Centre, MoAF
[3]

Fruit flies are ubiquitous and world over an important and one of the most destructive pests of wide range of fruits and vegetables. Among pest fruit fly species, Dacine fruit flies, one of the major subfamilies of the Tephritidae, are considered the most economically important group of Diptera (Fletcher, 1987).

In Bhutan the Chinese citrus fruit fly, *Bactrocera minax* (Enderlein) (Diptera:Tephritidae), also falling under the sub family Dacinae, is one of the most serious insect pest of Mandarins, *Citrus reticulata* Blanco. *B. minax* occurs most commonly in mid and high altitude orchards (above 1100 m) and has been reported to cause losses ranging from 35% to 75% (Van Schoubroeck, 1999). Fruit yield loss and damage primarily occurs when the female fruit fly deposits its eggs, below the rind of the fruit, with its ovipositor and the eggs hatch into larvae which feeds inside the fruit causing premature ripening and fruit drop.

Apart from various ecological studies, devising novel and improved control techniques has also been a major area of research focus in pest fruit flies. Therefore, a range of management options exists for this pest of economic importance. Among these, the most commonly used technique adopted widely in the least developed and developing regions of the world is the use of conventional pesticides as cover sprays. Cover sprays are effective in reducing losses due to fruit fly infestation, but at the same time carry a significant drawback. Impacts on human health, environment and non-target organism/beneficial organism are some of the many concerns associated with it. Due to this concern, cover sprays are losing its popularity and are increasingly being replaced with other softer control techniques such as protein bait sprays. Protein bait sprays have been proven to be very effective in controlling fruit fly when applied over large growing areas and over seasons. Female fruit fly require a source of protein for sexual development, and right after emergence are hungry for protein and are highly attracted to it. Therefore, protein baits mixed with minuscule amount of insecticide applied as spots attract large number of flies which feed on it and die. This technique significantly reduces fruit fly damage, amount of insecticide sprayed in the environment and the impact on human health and non-target organisms. Other techniques applied for fruit fly control, apart from cover sprays and protein bait sprays, are Cultural and Physical control, Biological control, Sterile Insect Technique (SIT) and Male annihilation technique (MAT) using parapheromones such as Cu-Lure and Methyl eugenol.

In Bhutan too, past research focused on devising appropriate control strategies for *B. minax* recommended the use of fortnightly application of protein bait sprays or cover spray with synthetic insecticide in conjunction with cultural practice such as collection and destruction of fallen fruits every 10 days (Dorji *et al*., 2006). However, apart from chemical control and cultural control, protein bait sprays does not appear to be a feasible control option because of non availability of cheap protein source and hence is not being currently implemented for field control of *B. minax*.

Fruit fly control has been evolving with research and adoption of environmentally friendly control strategies hence it warrants us to explore and devise interventions that are environmentally friendly and practical to the fruit fly species prevalent here. As *B. minax* overwinter in the soil and has a long pre-pupal period (Dorji *et al*., 2006) it is probable that appropriate interventions like application of cultural practices such as tillage during this period could cause significant mortality of *B minax* pupae due to natural predation and exposure to various abiotic factors. However, no empirical study hitherto has determined effects of such practices on mortality of *B minax* pupae. Therefore, this study observes the effect of application of soil tillage on pupal mortality of *B. minax*. If significant effect on the mortality of *B minax* is observed, this technique holds promise of being applied in conjunction with other control measures in reducing fruit fly population build up and damage.

The objectives of this study were to:

1. Determine the effect of tillage on the mortality of *B. minax* pupa present in the soil.
2. Determine the effect of natural predation in reducing *B. minax* pupal population in the soil.

MATERIALS AND METHODS

Study Site: The trial was carried out in a mandarin orchard in the Rimchu Valley, west of Punakha (89.87E/27.58N) with an altitude of 1300 m asl in 2001.

Experimental layout: In mid November, 24 square plots each measuring 0.5m by 0.5 m under different mandarin trees were marked by placing four wooden spikes of 0.5m length. These wooden spikes were used to

mark the designated squares under each mandarin tree. Prior to the experiment, the soil was tilled in these marked areas in order to provide a uniform surface area for the fruit fly larvae to pupate. Then 30 dropped fruits were randomly collected and introduced in each of these plots. These fruits were introduced for the larvae in the fruit to pupate in these marked plots.

Out of the 24 plots, 12 plots were covered with fine wire mesh (0.25mm by 0.25mm) and the other 12 were kept exposed. From the 12 covered plots 6 plots were tilled in mid January and were covered again. Similarly, 6 plots from the 12 exposed plots were tilled in mid January. A total of 180 dropped fruits were randomly collected and brought to the laboratory to determine an estimate of total number of pupae emerging from the cohorts of 30 fruits placed in the 24 plots in the field. Therefore, 30 fruits were separately placed in 6 different cages for the pupae to develop in the laboratory. The treatments were

T1= fully exposed fruits with no tillage applied
T2= fully exposed fruits with tillage applied in mid January
T3= fully covered fruits with no tillage
T4= fully covered with tillage applied in mid January
C= fruits brought to the laboratory and reared

In order to determine the effect of tillage on pupal mortality, in mid March each plot was sieved and the total number of pupae present was recorded. Similarly, total number of pupae obtained from the fruits in the laboratory was also counted and recorded.

Data analysis: Data analysis was carried out using SPSS statistical analysis software. Prior to analysis, normal distribution was tested using the Kolmogorov-Simirnov test and homogeneity of variances was tested using the Levene's test. In order to stabilize variances, the data was log transformed [log(x+1].

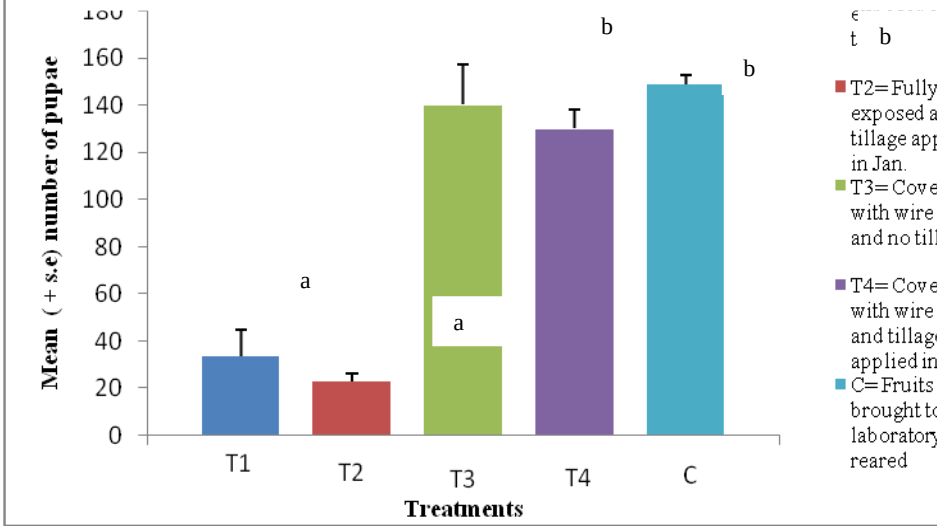
Data was subjected to an analysis of variance (ANOVA). When significant difference was detected by the ANOVA, treatment means were compared using Duncan's test. Differences in treatment means were considered statistically significant at the $P = 0.05$ level.

RESULTS AND DISCUSSION

A significant difference was detected between treatments with respect to the total number of pupae present ($F_{4,25} = 42.469$, $P = 0.000$). A Post-Hoc comparison of means (Duncan's test) showed a significant difference between plots that were covered with wire mesh and the ones left exposed. Significantly higher number of *B. minax* pupae was present in plots covered with wire mesh compared to the ones left exposed (Table 1). In addition, significantly higher number of pupae was collected from fruits reared in the laboratory than the ones left exposed in the field (Table 1). This result thus indicates that natural predation played a very significant role in reducing the number of pupae present in the soil. Various predators such as ants, spiders, carabid beetles, assassin bugs, staphylinid beetles and lygaeid bugs have been reported to play an important role in reducing fruit fly population through natural predation (Bateman, 1972; Allwood, 1997). Apart from this, chickens that are let free (runners) can also play a significant role in reducing the number of pupae present in the soil (personal observation).

Application of soil tillage did have some effect on pupal mortality, but this effect was not significant as the total number of pupae in plots that were exposed without tillage and the ones exposed and tilled in January did not vary significantly (Table 1). This indicates that tillage did not have any effect in reducing the number of pupae present in the soil. Though tillage is an important practice that enhances the overall health and yield of fruit crops, it may not be an effective control option in reducing the overall *B. minax* population in the field. Unlike cultural control method recommended for fruit fly control, such as collection and destruction of fallen fruits, the practice of tilling soil does not hold promise to be incorporated into an integrated control package for the Chinese citrus fruit fly.

Figure 1. Comparison of effect of tillage on pupal mortality of the Chinese fruit fly, *Bactrocera minax* (Enderlin) (Diptera:Tephritidae) in a mandarin orchard in Punakha



Bars between treatments with the same letter are not significantly different (Duncan's test on log [x+1] transformed data; $P = 0.05$)

CONCLUSION

This study was conducted to determine the effect of tillage and natural predation on the mortality of the Chinese citrus fruit fly, *B. minax*. It showed that tillage had no effect in reducing the number of pupae present in the soil. Thus, we can infer that soil tillage does not significantly facilitate natural predation by exposing the fruit fly pupae to various natural enemies. However, this study demonstrated the important role of natural predators in reducing the overall pupae number in the soil. It also indicates that within the orchard system natural enemies of the citrus fruit fly, especially predators, thrive in numbers that effectively regulate and bring down the number of fruit fly pupae pupating through winter in the soil. Hence, careful consideration should be given before advocating insecticide cover sprays so as to conserve natural enemies and facilitate natural control mechanism. However, up till now information on the presence of identified predators and their vital roles in natural control mechanism does not exist. Therefore, studies focusing on inventorying predators present within an orchard system can help better understand the natural control processes and possible fruit fly control interventions

employing natural control agents. In addition, future studies should focus on inventorying important fruit fly parasitoids present within our orchard system.

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Bulb Onions…..A potential crop for domestic market

Kinlay Tshering[1], Laxmi Thapa[2] , Durba Das Chettri[3],
Sonam Dema[4] and Kinley Wangmo[5]

ABSTRACTS

Six different onion varieties (hybrid + open-pollinated) in low, mid and high altitude area were tested with the objective to evaluate their production potential and to identify a suitable variety for different cropping season in Bhutan. There was a significant difference in average bulb weight and yield among the varieties evaluated in mid and high altitude areas. In high altitude areas, Top Keeper, Hi Keeper and Shenshu Yellow yielded significantly higher than Pune Red, Bombay Red and Sonic. In mid altitude areas, Sonic yielded significantly higher than Top Keeper, Hi Keeper and Shenshu Yellow, and they also yielded significantly higher than Bombay Red and Pune Red. All the varieties yielded better in mid altitude areas than in high altitude areas. The yield of Pune Red varied from place to place. Production was good at Tabji followed by Genekha and then Tendu. All these varieties can be successfully cultivated from March to August in high altitude areas and from October to June in mid and low altitude areas. Although the yields of Top Keeper, Hi Keeper, Sonic and Shenshu Yellow are significantly higher than Pune Red and Bombay Red, the two red varieties had the advantage of red skin colour which is preferred by the local consumers. . It was found that onions can be successfully cultivated after rice in mid and low altitude areas, effectively utilizing the fallow paddy lands during their rest period in winter and it can be also grown successfully in high altitude areas in rotation with rice or potato as a break crop.

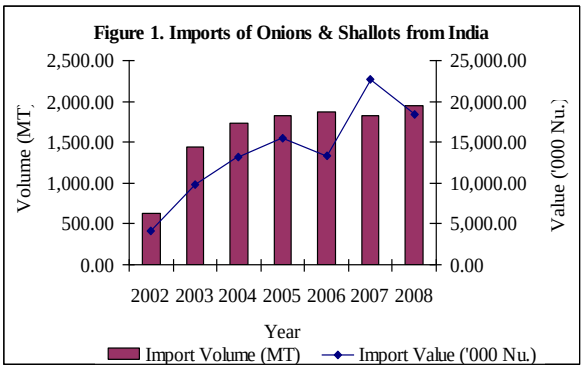
KEY WORDS: Bulb onion, Domestic market, Season, Production potential, Fallow wetlands, Varieties.

[1] Renewable Natural Resource Research Centre, Yusipang, CoRRB, Ministry of Agriculture
[2] Renewable Natural Resource Research Centre, Yusipang, CoRRB, Ministry of Agriculture
[3] Renewable Natural Resource Research Sub-Centre, Darla, CoRRB, Ministry of Agriculture
[4] Renewable Natural Resource Centre, Chengmari geog, Samtse
[5] Renewable Natural Resource Centre, Tala geog, Chukha

INTRODUCTION

Onion (*Allium cepa* L.) probably originated in Afghanistan, Iran and Pakistan (George, 1999). Today it is widely cultivated in many areas of the world including the tropics and the temperate regions. Until recently the cultivation of onions in Bhutan is limited, however, its use and demand is increasing with the change in Bhutanese cuisine. The very young plants, developing and mature bulbs are used in a variety of ways. Onion is one of the most important ingredients required while cooking any type of vegetable, fish and meat curries. Bhutanese cuisines like *momo, ema datsi, ezay* etc require lot of onions (Chhetri, 2009).

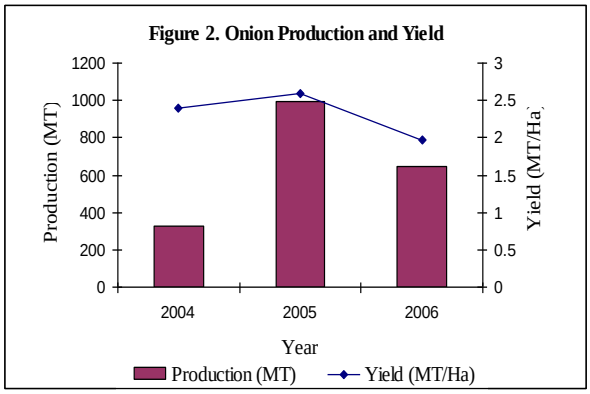
Generally, onion supply in Bhutan does not meet the national demand due to the small acreage of production, low yields and seasonal production. Thus, Bhutan has been importing substantial amount of onions and shallots from neighboring countries, especially India (Tshering *et al*., 2009). During the past seven years, annual onion imports have ranged from 600 to 2000 Mt. (Figure 1) and our domestic production and yield (Figure 2) is not increasing at par with the demand. About 74% of the onion demand is met through imports. This scenario indicates the domestic market potential, which is increasing every year.



Onion is a very high potential cash crop in Bhutan. Its market is fairly stable and seldom drops below Nu. 15/kg. Onion is one crop which stray cattle do not prefer to graze, and thus there is usually no need for an intricate fencing. It also has less pressure from insect pests and diseases. Further, the storage potential of the mature bulbs has led to onions becoming an important crop and it can be an added advantage especially to a landlocked country like Bhutan with limited and uncertain transport system.

Further, the limited land available for cultivation of crops is a major constraint in enhancing production. On the other hand, fallowing of land is on the rise and the paddy lands are mostly used for only one crop –

paddy, starting sometime in May to October and after that it is in most cases, a grazing area for stray animals. This fallow period is an area of untapped potential to enhance production.



Considering these advantages of growing and marketing onions, varietal and production trial in low, mid and high altitude area using both hybrid and open pollinated varieties was carried out. The objectives were to: a) evaluate the production potential of different onion varieties, b) identify a suitable variety for different cropping season in Bhutan, and c) to see the suitability of onion cultivation in rice-based cropping system.

MATERIALS AND METHODS

Bulb onion varieties (Hi-Keeper, Top Keeper, Sonic, Shenshu Yellow, Pune Red and Bombay Red) were obtained from Druk Seed Corporation, Paro. All the varieties after successful testing on research stations were further tested in the farmers' field under farmer's management by researchers and extension agents of the research sites. There were two sets of experiment. One set of experiment was to evaluate different onion varieties at three different locations (low, mid and high altitude) and the other set of experiment was to evaluate the production potential of a hybrid onion variety i.e. Pune Red in different locations.

The varietal evaluation for high altitude area was conducted at Namkar (2300 m asl) under Wangchang geog of Paro Dzongkhag between April and October 2008 and the varietal evaluation for mid altitude and low altitude area were conducted between October 2008 and June 2009 at Arikha (1160 m asl) under Darla geog of Chukha Dzongkhag and at Kirney (450 m asl) under Chengmari geog of Samtse Dzongkhag respectively. The production evaluation trial of Pune Red was evaluated at Genekha and Yusipang under Thimphu Dzongkhag, Tendu, Ugyentse,

Chargari and Chengmari under Samtse Dzongkhag and Tabji, Mirchimo and Lower Soureyney under Chukha Dzongkhag. The trial procedures and treatments were same in all the locations.

For the varietal evaluation, six varieties of bulb onion (Hi-Keeper, Top Keeper, Sonic, Shenshu Yellow, Pune Red and Bombay Red) were evaluated in a complete randomized block design with three replicates. At Namkar, the nursery was raised on 13th April, 2008 and then transplanted into the open field on the raised beds on 21st May 2008. At Arikha, the nursery was raised on 5th October, 2008 and then transplanted into the open field on the raised beds on 22nd November, 2008. At Kirney, the nursery was raised on 8th October, 2008 and then transplanted into the open field on the raised beds on 25th November, 2008. For the production evaluation trial, the nursery for high altitude sites (Yusipang and Genekha) was raised in March 2009 and the crops were harvested in September 2009 and the nursery for mid (Tabji, Mirchimo, and Lower Soureyney?) and low altitude sites (Tendu, Ugyentse, Chargari and Chenmari) was raised in October 2008 and the crops were harvested in May 2009. The entire nursery was established on raised beds using compost with line sowing and straw mulching. Onion seeds were sown at 1.5 cm depth in rows about 8 cm apart in the nursery bed. Nursery bed was irrigated immediately after sowing and then daily irrigated in the evening.

Each onion variety was planted to an area of 3 m^2 (3 m length with 1 m width) and the plant spacing was 15 cm plant to plant and 15 cm row to row. For each variety/treatment, there were 140 onion seedlings (20 plants per row x7 rows). Basal dose of 20:30:30 NPK and 10 MT organic fertilizer per acre at the second ploughing was applied. An additional 20 kg N per acre was applied 30days after transplanting. Two to three hand weeding were done during early crop growth stages depending upon the weed pressure. The plants were largely rainfed but were hand-irrigated as and when required. Crops were monitored by conducting field visits by researchers and extension agents together or by extension agents alone. The plants were monitored on monthly basis for bulb formation and for pest and disease infestation. Onions were harvested when the new growth has ceased and about 50% tops have fallen or broken “neck-fall”. The data was recorded from the whole trial plot for the varietal evaluation and from the crop cuts taken from the production evaluation trial plots.

Random crop cuts in quadrants of 1 m^2 with atleast 3 samples were recorded. Yield was based on fresh weight at the time of harvest.

MS Excel was used in compiling the data and then exported to GENSTAT for Windows, Version 3.2, Lawes Agricultural Trust, Rothamsted for bulb weight and yield analysis with the analysis of variance (ANOVA).

RESULTS AND DISCUSSION

The varietal evaluation in high and mid altitude area was very successful. However, the varietal evaluation in low altitude area was not successful because the collaborating farmer had problem in irrigating his trial field as desired especially at the time of bulb formation. However, the performance of Pune Red with other farmers having no irrigation problem was very successful.

Table 1. Yield parameters of bulb onion varieties at Arikha, Chukha

Variety	Av. bulb wt. (gm)	Yield (MT/Ha)
Top Keeper	233 a	85.2 b
Hi Keeper	237 a	93.3 b
Sonic	330 a	108.8 a
Shenshu Yellow	223 a	80.2 b
Pune Red	73 b	39.0 c

Within the altitude range, there was a significant difference in average bulb weight and yield between the varieties evaluated in mid and high altitude areas (Table 1 & Table 2). In high altitude areas (Namkar), Top Keeper, Hi Keeper and Shenshu Yellow yielded significantly

Table 2. Yield parameters of bulb onion varieties at Namkar, Paro

Treatment	Mean bulb wt (gm).	Yield (MT/Ha)
Top Keeper	150.0 a	59.3 a
Hi Keeper	145.0 a	55.0 a
Sonic	70.0 b	15.0 c
Senshu Yellow	145.0 a	55.0 a

higher than Pune Red, Sonic and Bombay Red. Sonic yielded the lowest with a yield of 15 Mt/ha. In mid altitude areas, Sonic yielded significantly higher than Top Keeper, Hi Keeper and Shenshu Yellow, and they also yielded significantly higher than Bombay Red and Pune Red.

Although not statistically evaluated but a comparison of the yield of all the varieties across different altitudes shows that altitude has an effect on the yield performance of all the varieties. Sonic variety performed the best in mid altitude areas and the worst in high altitude areas. In general, all the varieties except for Sonic yielded better in mid altitude areas than in high altitude areas. Pune Red and Bombay Red yielded very similar in both high and mid altitude areas thereby indicating their stability in yield performance across altitude zones.

Although the yields of Top Keeper, Hi Keeper, Sonic and Shenshu Yellow are significantly higher than Pune Red and Bombay Red in both the high and mid locations, the two red varieties have the advantage of red skin colour which is preferred by the local consumers. .

With regard to production trial using Pune Red, its yield varied from place to place (Table 3). Average yield was highest at Tabji followed by Genekha and then Tendu. The worst yield was from Ugyentse. This huge variation in yield could have been due to differences in crop management by different farmers and their differences in the level of knowledge on onion cultivation. Average across locations, Pune Red yielded around 45.7 MT per hectare.

Table 3. Average yield of bulb onion (Pune Red) in different locations

Dzongkhag	**Village / Geog**	**Av. yield (MT/Ha)**
Chukha	Mirchimo, Bongo	47.4
	Soureyney, Tala	38.8
	Tabji, Tala	70.3
Samtse	Tendu, Sibsoo	55.0

There was no major pest and diseases in any of the varieties across the altitude ranges tested. However, few instances of bolting were observed in all the varieties with autumn planting in mid and low altitude areas.

CONCLUSION

The research results clearly indicated the production potential of six bulb onion varieties. All these varieties can be successfully cultivated from March to August in high altitude areas and from October to June in mid altitude areas. Onions can be successfully cultivated after rice crop in low and mid altitude areas, effectively utilizing the fallow paddy lands during their rest period (November to June) in winter. It can be also grown successfully in high altitude areas in rotation with rice or potato as a break crop.

While cultivation of onion after rice is not a new innovation elsewhere, it is not a common practice in Bhutan. In a situation where enhancing production by utilizing fallow period of paddy lands amidst shortage of land for production, onion cultivation seems to be an alternative crop for the farmers because onion is comparatively easier to manage mainly due to less pest and disease incidences and minimal stray cattle damages. However, the cost of onion production needs to be studied.

As onion bulb formation is dependent on day length, there are specific daylength requirement groups for different latitudes. The range of cultivation areas of onion and its uses have led to a large number of cultivars and types. Therefore, in order to spur the growth of onion production, it is important to identify the right cultivars and types suited to Bhutanese conditions. We need to look into the availability of improved varieties uniquely adapted to the Bhutanese environment. Major improvements needs to be made in resistance to bolting among autumn planted varieties in mid and low altitude areas. The future onion varietal evaluation should look at responses to day length and temperature, it is recommended that the condition under which onion varietal trials are conducted should be more exactly defined (Currah, 1985). It may also be recommended that Bhutan also ventures into the development of F1 hybrid cultivars using cytoplasmic male sterility.

Onions are subject to wide swings in prices received by growers, depending on the production of onions in India and on the balance

between supply and demand at any specific time. Therefore, we need to adopt different approaches to minimize the risks associated with onion production and marketing. One approach is to produce the same acreage annually and to expect that the average income per year over several years will be positive. In addition, risk can be further minimized by producing different varieties (short, medium and long duration) for market over as long a period as possible in each year.

More recently it has been demonstrated that temperature also has an important influence in that the rate of bulb formation increases with temperature increase (Brewster, 1994). Therefore, we may need to revisit the sowing season (October in low/mid altitude areas and March in high altitude areas) if the rate of bulb formation increases only with temperature increase.

Since onion cultivation period seems to fit with the paddy- fallow system in mid and low altitude areas, it may be concluded that onion cultivation is up scaled with more farmers and taken on a commercial scale so that our domestic market demand is met with our local onion produce instead of importing from elsewhere.

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Field Application of FMDV-NS ELISA to Detect Antibodies against Non-Structural Proteins of Foot and Mouth Disease Virus in Bhutan

Jambay Dorjee[1], Dechen Wangmo[2], Samdrup Zangmo[3], S.B. Chamling Rai[4], Basant Sharma[5], Tenzin, Rinzin Pem[6]

ABSTRACT

Foot and Mouth Disease is endemic in Bhutan and the country experiences on an average about 10 outbreaks every year, especially in Chukha, Sarpang, Samtse and Samdrupjongkhar districts which share borders with India. The FMD virus serotypes O, A, C and Asia$_1$ were involved in previous outbreaks in the country but of late, serotypes O and Asia$_1$ are predominant. The control program is basically dependant on prophylactic vaccination since stamping out is not practicable in Bhutan. FMD vaccines which are highly purified and inactivated induce antibodies principally to the structural proteins of the virus, whereas the infected animals produce antibodies to both the structural and non-structural proteins. Therefore sero-conversion of susceptible animals to non-structural proteins (NSP) is considered indicative of FMDV infection. Studies conducted in experimentally infected animals with FMDV have demonstrated antibodies against NSPs indicating the potential use of the NSP 3 ABC ELISA to differentiate infected from vaccinated animals.

In this report we describe about the field study that we conducted in Bhutan using the NSP 3ABC as antigen in blocking ELISA for antibody detection in cattle following vaccination and/or infection with FMD virus. A total of 179 sera samples from cattle were collected from Trashigang, Samdrupjongkhar, National Nublang Breeding Far in Tashiyangphu, Chhukha and Zhemgang and subjected to antibody detection testing using commercially available CEDITEST® FMDV-NS ELISA test. Our result showed that the test can detect antibodies against FMDV as early as 5 days post infection and up to 382 days post infection. 80%, 16% and 35

[1] Renewable Natural Resources-Research Centre, Jakar
[2]Regional Livestock Development Centre, Kanglung
[3]Regional Livestock Development Centre, Tshimasham
[4]Regional Livestock Development Centre, Gelephu
[5]
[6]

% of infected cattle sample, non-vaccinated and naïve cattle sample, and FMD vaccinated cattle samples, respectively detected presence of antibodies, suggesting that the 3ABC ELISA can be a reliable means of detecting FMD infection in a vaccinated population. The probable reasons for detection of antibodies in the non vaccinated/naïve cattle and the vaccinated cattle are discussed in the paper.

KEY WORDS: FMD, FMDV-NS ELISA, Cattle, Bhutan

Introduction

Foot and Mouth Disease (FMD) is a highly contagious viral disease which affects all cloven-hoofed animals. The disease has an economically devastating impact on affected countries, mostly because of trade barriers that are imposed during the time of outbreaks (Sorensen et al., 1998; Bronsvoort et al., 2004). FMD is widespread in many parts of the world - Africa, Asia, Middle East and South America, where it is controlled by preventive vaccination (Sorensen et al., 1998). Within the European Union, vaccination against FMD has been banned since 31 December 1991 and the outbreaks are controlled by stamping out methods. However, the need for emergency vaccination, as an adjunct to stamping out cannot be ruled out (Sorensen et al., 1998).

There are seven distinct serotypes of FMD virus - O, A, C, $Asia_1$, SAT_1, SAT_2 and SAT_3. SAT 1-3 is prevalent in African countries (Sorensen et al, 1998).

In Bhutan, serotypes O, A, C and $Asia_1$ have been confirmed in animals. However, lately only serotypes O and $Asia_1$ are involved in outbreaks since 1998 in Bhutan. Since stamping out is not practicable in a country like Bhutan, the control program is basically dependant on prophylactic vaccination.

FMD vaccines available in the current markets are highly purified and inactivated. The vaccinated animals induce production of antibodies principally to the structural proteins of the viruses, whereas the infected animals produce antibodies to both the structural and non-structural proteins. Therefore sero-conversion of susceptible animals to non-structural proteins (NSP) is considered indicative of FMDV infection (Sorensen et al. 1998). The conventional serological diagnosis of FMD using the virus neutralization assay or ELISA relies on the detection of

antibodies to the structural proteins of the virus and does not distinguish between vaccinated and infected animals. Assays demonstrating antibodies against NSPs have the potential to differentiate infected from vaccinated animals (Sorensen et al. 1998).

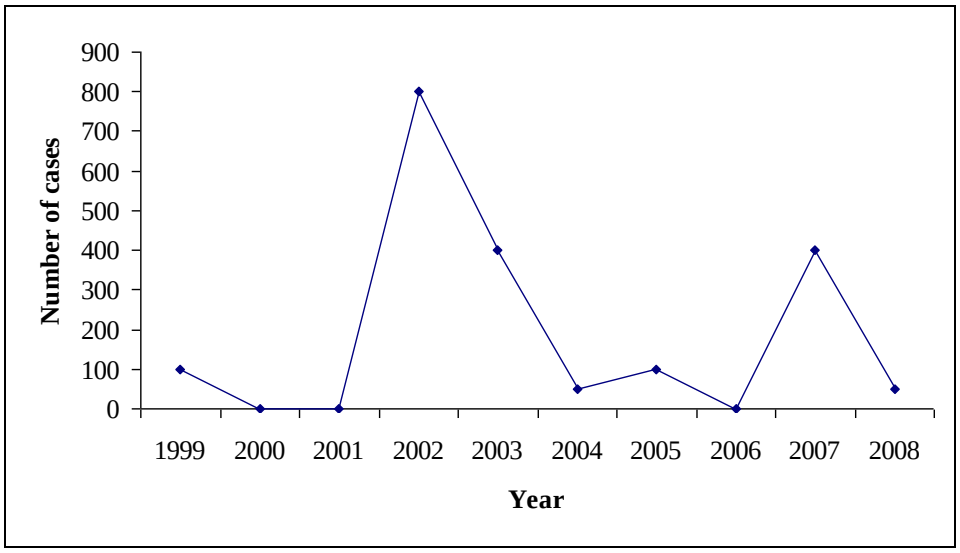


Figure 1: Number of FMD cases reported in cattle in eastern Bhutan between 1999 and 2000

In this study we describe about the use of the non-structural protein 3ABC as antigen in blocking ELISA for antibody detection in cattle following vaccination and/or infection with FMD virus in Bhutan. The main objectives of the this study are: (1) to determine the test ability to differentiate between infected from vaccinated animals; (2**)** to assess the field applicability of the CEDITEST®FMDV-NS ELISA kit for detection of antibodies against NSP of FMD virus in Bhutan by assessing its sensitivity and specificity; (3) to determine the earliest and the longest periods for 3 ABC antibodies detection in FMD infected animals; and (4) to distinguish the FMD infected/convalescent animals from vaccinated animals for monitoring virus presence or circulation in the study area. The findings from this study are expected to facilitate the control and eradication of FMD in the country.

Materials and Methods

Study area and sources of samples

A total of 179 serum samples were collected from cattle irrespective of breed, age and sex from Trashigang, Samdrupjongkhar, Chukha and Zhemgang districts and National Nublang Breeding Farm (NNBF), Tashiyangphu in Trashigang (Table 1 and 2). Chukha and Zhemgang districts were included in the study since the two districts had experienced the most recent FMD outbreaks in the country. We designed our study into three groups and collected the samples accordingly: 1) sera samples from non-vaccinated and naïve cattle; 2) sera samples from FMD vaccinated cattle at various post vaccination period, and 3) sera samples from FMDV infected cattle at various post infection periods (See Table 1 and 2). The samples from non-vaccinated and naïve cattle serve as control while samples from vaccinated cattle are the test samples in this study. The non-FMD vaccinated animals are those which had never been vaccinated against FMD while the naïve animals are those which had never been exposed to FMDV infection or FMD vaccination. FMDV infected animals included those cattle which were exposed to FMDV as a result of FMD outbreaks and showed clinical signs and symptoms of FMD.

Table 1: Serum samples collected from non-FMD vaccinated/naïve cattle and FMD vaccinated animals (Polyvalent FMD vaccines used)

Sample ID	Dzongkhag	Geog	Village/location	No of sera samples collected	Time of collection (days after vaccination)	Remarks
Sample 1	Samdrup Jongkhar Trashigang	Serthi Khaling	Menjiwoong NNBF, Tashiyangphu	44		Non-vaccinated/ naïve animals
Sample 2	Trashigang	Samkhar	Pam	11	139	FMDV free cattle
Sample 3	Trashigang	Khaling	NNBF. Tashiyangphu	41	224-226	FMDV free cattle
Sample 4	Trashigang	Khaling	Lemi	22	365	FMDV free cattle
Sample 5	Trashigang	Khaling	NNBF Tashiyangphu	6	394	FMDV free cattle

Table 2: Serum samples collected from FMDV infected cattle in Chhukha and Zhemgang

Sample ID	Dzongkhag	Geog	Village/location	No of sera samples	Time of collection
Sample 6	Chhukha	Bongo	Rani camp area	10	5 dpi*
	Zhemgang	Bardo	Langdurbi	3	15 dpi
	Chhukha	Chapcha	Chapcha	11	23 dpi
	Chhukha	Bongo	Namchilakha, Beri road area	14	59 dpi
	Zhemgang	Bardo	Langdurbi	6	282 dpi

*dpi = day post infection

Laboratory test

All 179 sera were subjected to antibody detection testing using CEDITEST®FMDV-NS ELISA as per the test protocols of the kit. The CEDITEST®FMDV-NS ELISA is a commercially available kit produced by Cedi diagnostics B.V. It is a blocking ELISA which detects antibodies against FMD virus non-structural proteins 3ABC. ELISA plates supplied in the kit have been coated with 3ABC specific monoclonal antibodies followed by incubation with the 3ABC protein.

Test calculation and interpretation of results

The optical density (OD) was measured at 450 nm using the ELISA plate reader. The mean OD_{450} value of wells A1 and B1 (negative control wells) (= OD max) were calculated. The Percentage Inhibition (PI) value of test samples and controls were then calculated using the following formula:

$$PI = 100 - \left(\frac{OD_{450} \text{ of test or control sample}}{OD_{450} \text{ max}}\right) X100$$

The assay was accepted if OD_{450} or PI values of controls met the following criteria:

a) The mean OD_{450} of wells A1 and B1 (negative control, OD_{450} max.) is > 1.000
b) The mean PI value of the weak positive control is > 50%
c) The mean PI value of the positive control is >70%

The mean Percentage Inhibition (PI) of each sample was calculated in Microsoft excel and then plotted using a Box and Whisker Plot in excel

Box Plot template. The results were interpreted as: i) PI value less than 50% were considered as negative (indicating absence of antibodies to FMDV 3ABC present); ii) PI value greater than or equal to 50% were considered as positive (indicating presence of antibody to FMDV 3ABC), and iii) if the OD of a test sample is higher than the OD_{450} max, the PI of this sample was interpreted as 0%.

Results and discussion

All sera samples were successfully tested in the laboratory. Figure 2 shows the box and whisker plot to graphically depict the summary statistics (median, first and third quartiles, inter-quartile range, outliers, skewness and the tails of the distribution) of the PI values for the various sera samples tested for antibodies against 3 ABC proteins.

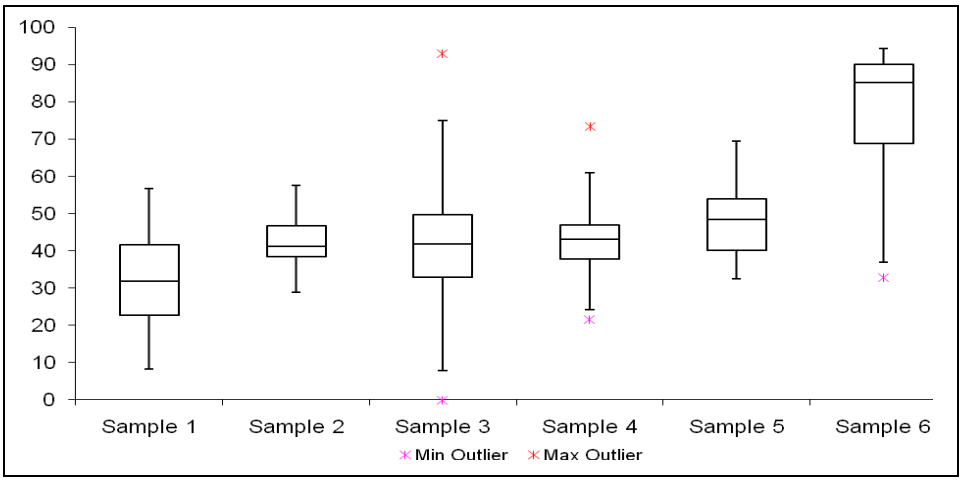
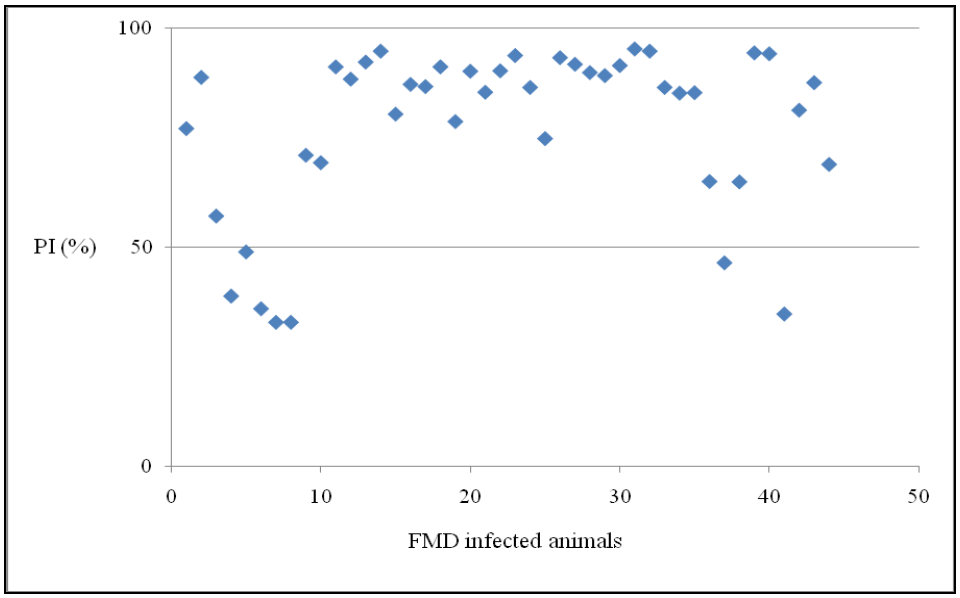


Figure 2: Box and whisker plot of the PI values (%) for different groups of samples tested for antibodies against 3 ABC proteins. The summary results of the tests are shown in the Table 3

Table 3: Summary results of the test and interpretation

Sample ID	Percentage of total serum samples with PI values (> 50 %)	Interpretation
Sample 1	18.8	Positive antibodies against FMDV 3ABC proteins
Sample 2	18.8	
Sample 3	24.4	
Sample 4	33.3	
Sample 5	18.2	
Sample 6	84.1	

Figure 3: Percentage Inhibition for FMDV infected animal samples



Overall, 20.2 % of the serum samples from non-vaccinated/naïve and FMD vaccinated animals had PI > 50 %, indicating positive antibodies against FMDV 3 ABC proteins. The result implies that the sampled animals were exposed to FMDV previously. Since we did not collect the history of the source of animals, it is probable that the animals might have been exposed to FMDV in their previous farms or village. The other possibility could be due to the varying quality of the vaccines used in Bhutan and need to be assessed in future studies.

Sensitivity and specificity

The sensitivity of 3ABC ELISA for cattle infected with FMDV were calculated (Table 4). The sensitivity was 100 % in sera collected and tested 2 to 8.4 weeks FMD post infection. The sensitivity was 50 % in sera collected and tested 5 days post infection and 66.7 % in sera collected and tested 382 days post infection. The lower sensitivity obtained in earlier and later stages of infection is not related to particular serotypes but might have been due to delayed or weak responses to NS proteins or due to poor quality of sera. The specificity for 3ABC ELISA was calculated for the non-vaccinated/naïve animal group only and the specificity were found to be 84.1 % (Table 5).

Table 4: Determination of sensitivity of 3ABC ELISA from FMDV infected animals samples

Post Infection Village/geog/District	5 days Ranicamp Bongo Chhukha	15 days Langdurbi Bardo Zhemgang	23 days Chapcha Chapcha Chhukha	59 days Namchilakha Bongo Chhukha	382 days Langdurbi Bardo Zhemgang
Number Positive	5	3	11	14	4
Number Negative	5	0	0	0	2
Total samples	10	3	11	14	6
Sensitivity (%)	50	100	100	100	66.7

Table 5: Determination of specificity of 3ABC ELISA from naïve and non vaccinated animals samples

Post vaccination Villages/Geog/District	None/Naïve NNBF/Serthi (T/Yangphu & S/jongkhar)	139 days Pam Samkhar Trashigang	224-226 days NNBF Tyangphu Trashigang	365 days Lemi Khaling Trashigang	394 days Langdurbi Bardo Zhemgang
Number Positive	7	2	10	4	2
Number Negative	37	9	31	18	4
Total samples	44	11	41	22	6
Specificity (%)	84.1				

Early and late antibody response of FMDV infected animals

The earliest antibody response against the NSP (3ABC) in cattle was measured at day 5 post infection (5 out of 10 samples) in this study. The response to 3ABC in cattle could be detected as early as 7-10 days post infection and subsequently decreased gradually (Sorensen et al., 1998). Although the results are comparable with those obtained by others, a decreased sensitivity was seen in early detection of antibody response to 3ABC in cattle. The longest period for antibody detection was 382 days post infection (4 out of 6 samples) in this study. The sera for longer periods than 382 days post infection were not available for analysis in this study. However, experimental sera collected elsewhere 395 days post infection showed strong positive results (Sorensen et al., 1998). The determination of antibodies late post infection also indicates that antibodies against NSPs generally last long and possibly longer than antibodies against the structural proteins (Sorensen et al., 1998).

Field applicability of CEDITEST®FMDV-NS ELISA

The performance of several ELISAs for detection of antibodies to NSPs of FMD virus has been evaluated for sera collected from experimentally FMDV infected animals and has shown that tests developed to detect antibodies to the poly-protein 3ABC or part of this protein have so far been the most successful as compared to liquid phase blocking (LPB) and solid phase blocking (SPB) ELISAs (Sorensen et al., 1998). The practical use of CEDITEST®FMDV-NS ELISA is immense and in Bhutan, perhaps its major use at present may be to serve as a rapid diagnostic kit to confirm FMDV infections in all susceptible animals. It can be used to differentiate infection from vaccination as part of sero-monitoring and surveillance in the field at the national or regional level. However, due to its low sensitivity, especially early in infection, the assay is recommended only for screening herds of animals and not on an individual animal basis (Sorensen et al., 1998). Identifying animals that have been infected with FMDV is important for the control of FMD as recovered cattle and sheep frequently remain carriers of the virus (Alexandersen et al., 2003) and consequently may become the source of new outbreaks of the disease. The diagnostic challenge is to distinguish non-infected, infected and vaccinated animals since latter groups have neutralizing antibodies in their sera (Clavijo et al., 2004). Several ELISAs have been developed to distinguish infected animals from those that have been vaccinated, all based on the detection of antibodies to the NSPs of FMD virus (Bermann et al., 2000: Shen et al., 1999: Sorensen et al., 1998). Tests to detect antibodies to the poly-protein 3ABC or part of this protein have so far been the most successful (Mackay et al., 1998). The 3ABC ELISA can distinguish between vaccinated and infected cattle but not between carriers and non-carriers (infected but totally recovered), and it constitutes a reliable means of detecting infected animals in a vaccinated population, irrespective of the vaccine serotype involved.

Bhutan is endemic to FMD and vaccination forms an integral part of control program in the country. There is a need for reliable and rapid diagnostic techniques to detect FMDV in the field during outbreaks which can differentiate infected from non-infected and vaccinated animals and also as a tool for sero-monitoring and surveillance to plan effective control measures against FMD in the country. The conventional serological diagnosis of FMD using ELISA, which is used in Bhutan at present relies on the detection of antibodies to the structural proteins of the virus and does not distinguish between vaccinated and infected

animals. The use of FMD-NS ELISA would be the most appropriate diagnostic method for detecting FMDV in the country.

CONCLUSION

Our study showed that the CEDITEST®FMDV-NS ELISA test kit can detect antibodies against FMDV as early as 5 days post infection and as late as 382 days post infection. Thirty seven out of forty four infected cattle and also vaccinated cattle produced positive results, suggesting that the 3ABC ELISA can be a reliable means of detecting FMD infection in a vaccinated population.

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Interim Thinning Results on Bluepine Forest Productivity and Stability in Khotokha West Central Bhutan

Mani Ram Moktan[1], Rinzin Dorji[2], YogRaj Chhetri[2], Purna Bahadur Gurung[2]

ABSTRACT

The monospecific Bluepine forest belt that lies between 1800-2800m altitudes comprised of high density pole-size stock stands and if un-thinned remains unproductive and unstable. Higher interspecific competition on resource requirements due to similar genetic composition results in higher mortality rates. Artificial thinning of the high density stands improves the productivity and stability. The study aims to quantify the effect of thinning intensities on productivity and stability in order to improve Bluepine forest management in Bhutan. At Khotokha forest management unit, three permanent thinning observation plots of size 60m x 60m with an inner plot of 40m x 40m were established. Three thinning treatments; no thinning (control), moderate thinning (25% of initial stand volume cut) and heavy thinning (30-35% of the initial stand volume cut) were implemented. There was significant difference between the treatments with moderate thinning performing better in terms of net increase in stand volume and stand stability after the inception of thinning operation. The conclusion is based on interim results of 2000-2007. Regular monitoring and additional data collection is suggested.

Key words: Thinning; Khotokha; Bluepine; Western Bhutan.

INTRODUCTION

Bluepine (*Pinus wallichaina* A.B. Jackson) is one of the pioneer and commercially important species of temperate conifer forests in Bhutan. It grows between 1800 and 2800m above sea level (a.s.l) altitudes and some studies have revealed to grow up to 4400ma.s.l in Nepal (Jackson, 1987). As pioneer species: Bluepine demands light and attains greater than 150 cm dbh and 30m height; matures between 90-120 years; and prefers dry

[1] Council for RNR Research of Bhutan
[2] RNR-R&DC Bajo, Wangduephodrang

well-drained soils (Negi, 1985). It regenerates profusely and colonizes fallow areas and scrub forests. At lower elevation, bluepine forms monospecific stands, whereas at higher elevation mixed conifer forests it mixes with other conifer associates. Bluepine trees of aged 10 years and below are less sensitive to fire (Moktan, 2000) and browsing by cattle.

Bluepine has many uses in Bhutan. It is used for house construction timber such as beam, plank, scaffolding and pole. A study conducted by Moktan et al (2009) reports Bluepine as preferred species than hemlock and spruce and trees are straight and, clean bole. Besides timber, local communities collect bluepine leaf litter for cattle bedding for fertilizing agricultural farms (Sargent et al., 1985). The aggressive and endurance nature of bluepine growing in open ground and scrub forests give rise to high density monospecific stands within its habitat range. The bluepine stands, if un-thinned remain unproductive and unstable. The observations made in Bumthang indicated that Bluepine stands suffer from interspecific competition during the stand initiation stage (Rosset and Rinchen, 1999). Without proper tending and thinning, the stand may not yield desirable increment and increases mortality and instability. The high interspecific competition on resource requirements due to similar genetic composition results in higher mortality rates and also increases the fuel-loads thereby increasing vulnerability of the forests to fires. Thinning of high density stands improves the productivity and stability and augments the policy of rural timber supply by the Department of Forests and Park Services. The objectives of the study are:

- To quantify the effect of thinning on productivity and stability of Bluepine forests at Khotokha.
- To improve silvicultural knowledge on Bluepine forest management in Bhutan.

MATERIALS AND METHOD

Study area

The trial is located 2 - 3 kilometers away from Tashi La cable logging depot near Soebasa sawmill (Fig. 1). The altitude is approximately 2780ma.s.l. The site has moderate slope and west facing aspect. Soil is deep, well-drained and fertile. The monospecific bluepine forests at Khotokha appear to transcend from natural pastures. The stand age

appears between 18-20 years old from the estimates of branch whorls. Annual temperature and precipitation data are not available.

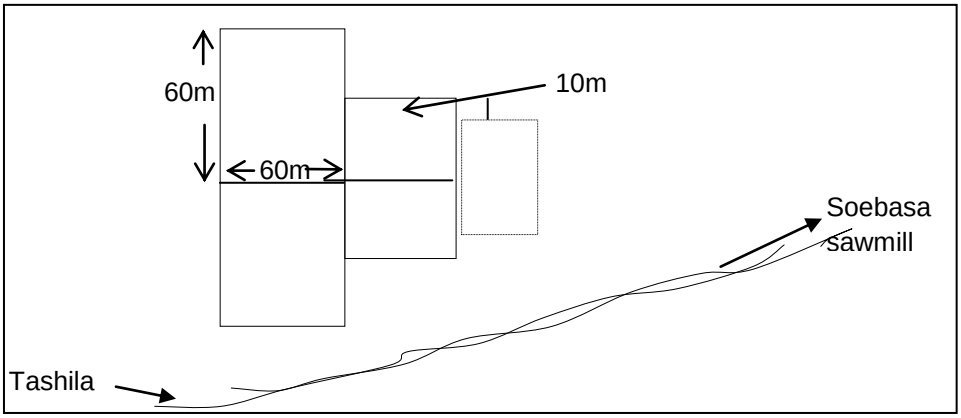

Fig.1. Map of layout of trial plots in Khotokha FMU

At Khotokha, three permanent thinning observation plots were established in 2000. The size of the plot is 60m x 60m (3600m^2) with an inner plot of 40m x 40m (1600m^2) with a buffer zone of 10m around the plot. Three thinning treatments; no thinning or control (T1), moderate thinning (T2) i.e., about 25% of the initial stand volume cut and, heavy thinning (T3) i.e., 30-35% of the initial stand volume cut were implemented. Weak and dead trees were removed leaving behind the healthy and vigorous ones. The actual data collected during the first thinning schedule shows that 22% of the initial stand volume (41m^3/ha) in T2 was already cut and 3% only remains to be cut during the second schedule. In heavy thinning, 36% of initial stand volume was cut exceeding the prescribed limit of 30-35%. This does not allow room for second cut in T3. All trees (≥10cm dbh) in the inner plot were numbered and their dbh (cm) and height (m) measured before and after thinning in accordance with the schedule of operation. The proposed duration of the trial is twenty-five years (2000 to 2025). The duration may be shortened if clear results are achieved earlier. The plots were laid out in March 2000 in collaboration with local foresters of the Wangdue Forest Division. The experimental forests were prevented from illicit cutting to the extent possible. The first thinning of trees was carried out in 2000 and successive data were collected in 2004 and 2007.

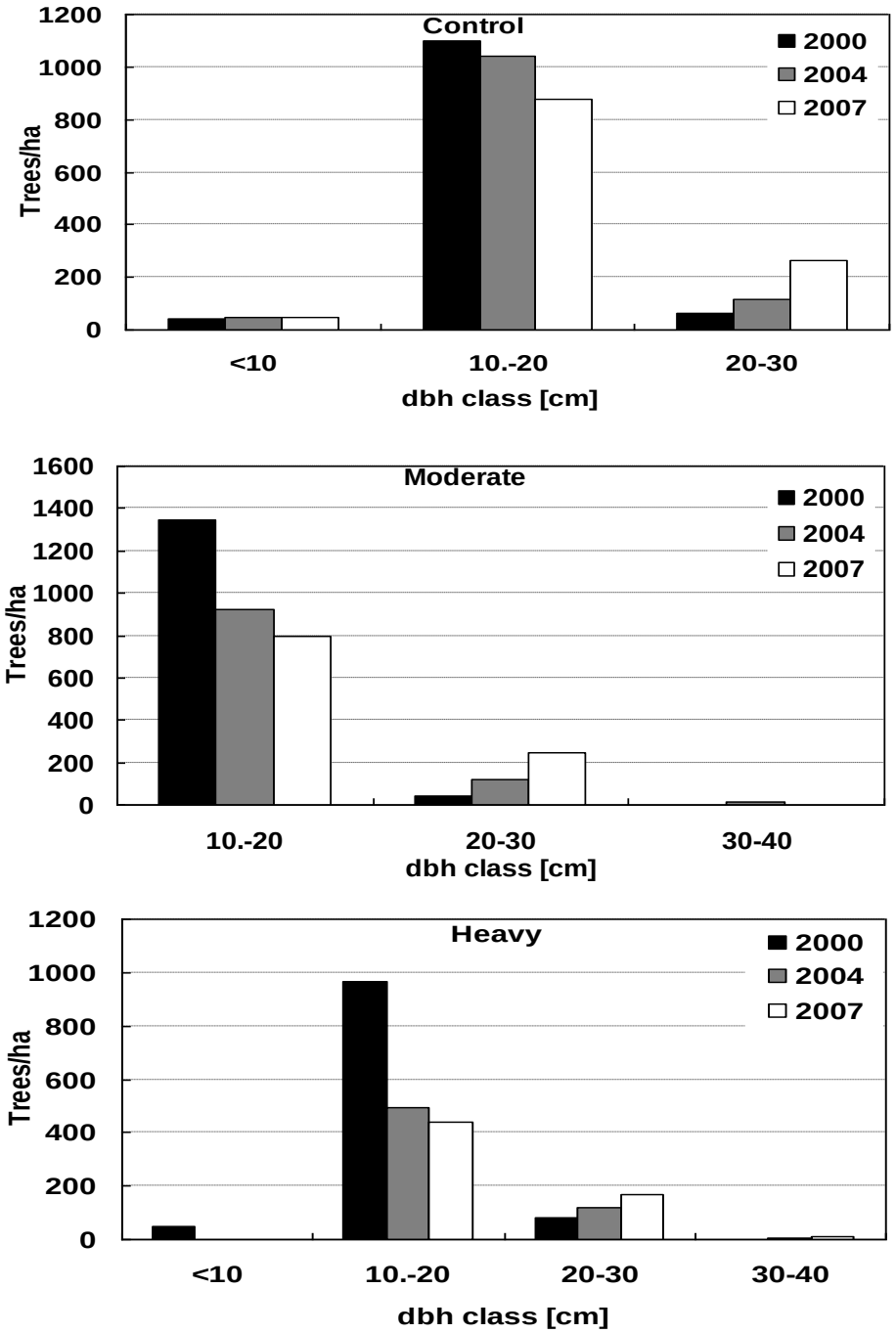

Fig.1. Dbh frequency distribution of trees in three thinning intensities of Bluepine stands.

Data analysis

Data analysis was performed using SPSS 13.0 (SPSS Inc., 2004). Dbh, height, tree densities, basal area, stand volume and slenderness coefficient was compared using the non-parametric Kruskal-Wallis test to observe difference amongst treatments. Prior to analysis, data were subject to normality test. Stand stability were assessed using the slenderness coefficient calculated as the ratio of height (cm) in relation to dbh (cm). Trees with slenderness coefficient greater than 100 indicate unstable, between 80-100 critical, and less than 80 stable. For some trees, tree height and dbh recorded in 2004 were found to be inconsistent with 2000 data due to human error. The 2000 data is therefore used as covariate in the analysis of variance (ANOVA).

RESULTS AND DISCUSSION

The *dbh* frequency distribution of trees by thinning intensities is shown in Figure 1. There was no significant difference in the number of trees between thinned and un-thinned Bluepine stands though half of the trees were cut in heavily thinned stands compared to un-thinned stands (Table 1). No significant difference was detected in tree densities in 2007 as well (Table 2). This indicates that thinning has little effects on tree densities which may attributes to in-growth. Rai et al (2008) pointed out that there was a quick recovery of stem densities in moderately thinned plots compared to heavily thinned plots at Hurchi, Bumthang.

Table 1. Mean (± s.d) of individual tree attributes by thinning intensities in 2004

Stand attribute	Thinning intensities			*Kruskal-Wallis test*	
	Control	Moderate	Heavy	*H*	*P*
Dbh (cm)	14.86±3.98	12.51±7.43	9.14±8.76	38.29	0.000**
Height (m)	8.48±2.20	9.09±5.40	5.9±5.36	43.80	0.000**
Density (trees ha^{-1})	301±496	264±443	155±232	0.069	0.966
Slenderness coefficient	57.27±14.07	57.67±33.46	38.49±34.48	40.36	0.000**
Basal area ($m^2 ha^{-1}$)	0.11±0.05	0.10±0.08	0.07±0.10	39.81	0.000**
Volume ($m^3 ha^{-1}$)	1.13±0.31	1.05±0.64	0.73±0.70	32.52	0.000**

*** Differences are significant at P < 0.001*

Table 2. Mean (± s.d) of individual tree attributes by thinning intensities in 2007

Stand attribute	Thinning intensities			*Kruskal-Wallis test*	
	Control	Moderate	Heavy	*H*	*P*
Dbh (cm)	16.81±5.03	13.54±8.14	10.45±9.84	31.92	0.000**
Height (m)	13.56±3.03	10.59±6.00	7.45±6.67	78.10	0.000**
Density (trees ha^{-1})	298±403	261±377	155±203	0.000	1.000
Slenderness coefficient	80.95±20.77	61.93±36	42.33±38.05	86.49	0.000**
Basal area ($m^2 ha^{-1}$)	0.15±0.07	0.12±0.09	0.10±0.11	31.48	0.000**
Volume ($m^3 ha^{-1}$)	10.29±3.09	8.23±4.87	6.19±5.85	40.86	0.000**

** *Differences are significant at P < 0.001*

There was significant difference (P > 0.001) in dbh, height, slenderness coefficient, basal area and volume of individual trees amongst three thinning intensities in 2004 (Table 1) and remain consistent in 2007 as well. After the thinning operations were performed in 2000, substantial volume increase was detected in 2007 from 2004. The ANOVA results on stand volume shows significant difference ($F_{2, 564} = 38$, $P < 0.001$) between three thinning intensities in 2007 (Table 3). The net increase in stand volume was highest (96%) in moderately thinned stands (Table 4). Similar study conducted by Rai et al (2008) pointed out that there was a rapid increase of stand volume in moderately thinned stands compared to heavy and control plots after thinning operations at Hurchi, Bumthang. Accordingly Rosset and Rinchen (1999) recommended a moderate thinning of Bluepine stands based on volume increment, stand stability and economics of thinning operations.

Table 3. ANOVA of stand volume ($m^3 ha^{-1}$) by thinning intensities

Source	SS	DF	MS	F	P
Model	4196	3	1399	75	0.000
Intercept	94	1	94	5	0.026
Volume/ha	2795	1	2795	149	0.000**
Treatment	1435	2	718	38	0.000**
Error	10567	564	19		
Total	14763	567			

** *Differences are significant at P < 0.001*

Table 4. Percent change in stand basal area and volume by thinning intensities

Thinning regime						
Control	2000	2004	Change (%)	2007	Change (%)	Net change (%)
Basal area ($m^2 ha^{-1}$)	18	20	10	25	20	30
Volume($m^3 ha^{-1}$)	192	185	-3.8	1718	89	85
Moderate						
Basal area ($m^2 ha^{-1}$)	23	22	-4.5	26	15	11
Volume($m^3 ha^{-1}$)	41	220	81.4	257	14	96
Heavy						
Basal area ($m^2 ha^{-1}$)	18	13	-38.5	17	24	-15
Volume($m^3 ha^{-1}$)	32	124	74.2	154	19	94

Slenderness Coefficient

The slenderness coefficient decreases in moderate and heavy thinning stands compared to un-thinned stands from 2000-2007 (Fig. 2). This indicates that un-thinned stands appear to become more unstable compared to thinned stands. Earlier studies conducted by Rai et al (2008) reported that control treatment had the highest ratio of unstable trees than the moderate and heavy thinning intensities.

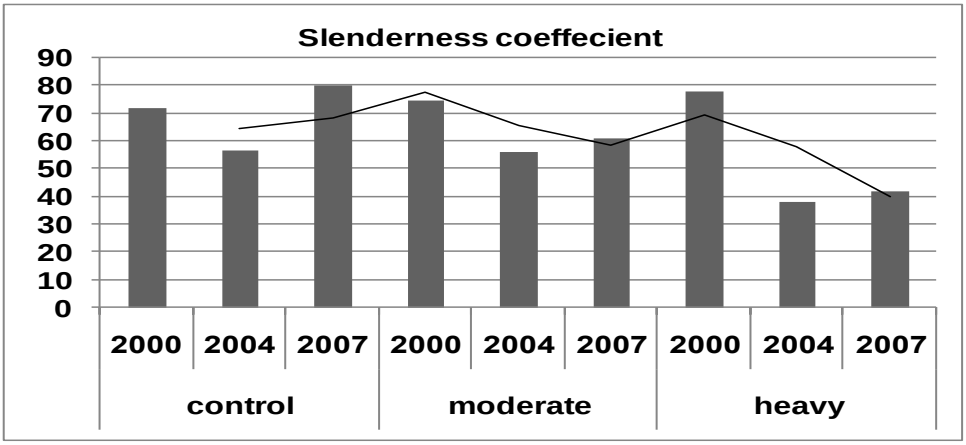

Fig. 2. Slenderness coefficient by thinning intensities of Bluepine stands.

CONCLUSION

Moderate thinning stands performed comparatively better with respect to volume and slenderness coefficient. This indicates that thinning increases volume and stand stability of moderately thinned stands. The inference is based on the interim results of 2000-2007 measurement. We suggest that the data collection at regular intervals be carried out with additional 3% volume removal in moderate stands and none in heavy thinning stands.

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Effects of thinning intensities on productivity and stability of bluepine forests

Prem Bahadur Rai[1], Andras Darabant[1] , Dorji Dukpa[1], Tshewang Dorji[1], Otto. Eckmüllner[2], Sangay[1], Georg Gratzer[2], Kinley Tenzin[1], Anton Bürgi[3], Tek Bahadur Rai[4], Yog Raj Chhetri[5]

ABSTRACT

This paper provides a summary of results from three existing blue pine thinning trials in Bhutan. The objectives are to quantify the effects of thinning treatments on productivity and stability of bluepine stands. The trials were established in the blue pine dominated valleys of Bumthang (Hurchi), Thimphu (Taba) and Wangdi Phodrang (Khotokha). In Hurchi and Khotokha two thinning intensities, (heavy and moderate) were applied and results showed that individual tree growth did not differ between thinning intensities, however, mean annual increment at stand level was more than double in moderate thinning treatment at Hurchi compared to heavy thinning, while both treatments were superior compared to no thinning (control). At Khotokha, time since thinning and the number of thinning entries did not allow for significant differentiation between treatments. At Taba, standing volume in the 4x4 spacing treatment was significantly lower than in the control treatment, while there was no difference between other treatments, from the initial standing volume in 1988. Findings indicate that moderate thinning (25% removal of standing volume) in blue pine forests increases gross volume and stand stability, minimize fire hazard and mortality, attains faster merchantable size timber and provide financial returns.

KEY WORDS: Blue pine, thinning intensity, stand stability, stand yield.

[1] RNR-RC Jakar, Bumthang, Bhutan
[2]BOKU-University of Natural Resources and Applied Life Sciences, Department of Forest and Soil Sciences, Inatitute of Forest Ecology, Vienna, Austria
[3] WSL Birmensdorf, Switzerland
[4] RNR-RC Yusipang, Thimphu, Bhutan
[5] RNR-RC Bajo, Wangduephodrang, Bhutan

INTRODUCTION

Bluepine (*Pinus wallichiana* A.B. Jackson) forms monospecific stands in secondary, even-aged forests, which represent roughly 5% of the total forest area of Bhutan (LUPP, 1995). The species occurs in inner dry valleys in the cool temperate regions at altitudes ranging from 2300 m a.s.l (above sea level) - 3100 m a.s.l with precipitation ranging from 450-1500 mm/year (Grierson and Long, 1983). Bluepine is an early successional component in mixed conifer forests. Although large-seeded, it compensates its resulting lower dispersal distances with zoochorous seed dispersal mechanism and can thus quickly colonize disturbed sites. In later succession stages, it is replaced by spruce and hemlock, the latter two being late successional component in the mixed conifer forests of Bhutan. The highly shade intolerant bluepine (Gratzer et al., 2004) proved to be a strong pioneer colonizing seral habitats in Nepal after the destruction of primary forests (Ohsawa, 1986). Observations made in Bumthang indicated that bluepine stands tend to remain densely stocked during stand initiation (pole-size) leading to excessive mortality and instability (Rosset and Rinchen, 1999). The high intraspecific competition and mortality rates increase fuel loads and thus there is risk of forest fires. Artificial thinning can partially compensate the high demand for pine timber and improve stand stability and reduce mortality and fire hazard (Ritchie et al., 2007) in densely stocked stands. If properly conducted, thinning also results in the improvement of timber quality and the concentration of increment on a smaller number of merchantable size trees. Thinning operations temporarily reduces stand productivity due to the removal of stems. However, these reductions are compensated through higher productivity of the remaining stand and through reduced mortality (Köstler, 1990). Spacing and pre-commercial thinning have been empirically shown to increase stand stability against stem breakage and to a lesser extent to wind throw (Achim et al., 2005). The specific objectives of the trial were to quantify the effects of thinning treatments on productivity, stability, in-growth and mortality of young bluepine stands.

MATERIALS AND METHOD

Location

Hurchi

The trial is located above Hurchi inside Karshong FMU in Chumey valley of Bumthang at an altitude of 3140 m.a.s.l. on a gentle east facing slope. The area is dominated by secondary, mono-specific blue-pine forests regenerating on an abandoned agricultural land after cultivation. Stands are relatively homogenous in age and structure and were vulnerable to snow breakage and wind throw. The trial was established in 1988. Dendrochronological analysis showed that the majority of the trees established in the period 1961-1966.

Khotokha

The research area is located about 2-3 kilometres from Tashi La near the road leading to Soebasa sawmill at an altitude of 2780 masl. The site has gentle to moderate slope with a west to southwest facing aspect. Site conditions are similar to Hurchi. The area is dominated by secondary, mono-specific bluepine forests with occasional mixing of oak (*Quercus semicarpifolia*). The trial was established in 2000. Dendrochronological analysis showed that the majority of trees regenerated in the period 1980-85.

Taba

The trial is located at 2450 masl near Taba, Thimphu and was established in 1988 on a moderate north-facing slope. Annual precipitation is 960 mm/year, most of which falls during June-September. Dendrochronological analysis showed that the majority of the trees established in 1963-1968.

Research design and measurement

Hurchi and Khotokha

In unmanaged young bluepine stands (age 20 years), 3 rectangular plots of size 60m x 60m were established in 1988 at Hurchi and 2000 at Khotokha. Recordings were done in 40m x 40m plots after excluding 10m as buffer zone. The thinning treatments were: moderate thinning (25% of standing volume cut), heavy thinning (35% of standing volume

cut) and no thinning (control) (Table 1). The trial design lacks replications.

Table 1. Thinning treatments in Hurchi and Khotokha

	% volume removed							
	Hurchi				Khotokha			
		treatment				treatment		
	Year	moderate	heavy	control	Year	moderate	heavy	control
1. thinning	1988	24.7	34.6	0	2000	17.7	34.7	0
2. thinning	1991	14.8	18.1	0				
3. thinning	2005	24.7	15.4	0	n.a.			
Total		62.4	68.1	0	Total	17.7	34.7	0

n.a. denotes not available

All trees above 10cm dbh in the 40mx40m plots were numbered at the start of the experiments. Trees having reached the 10cm dbh limit at later recordings were added.

At Hurchi, dbh was recorded in 1988, 1991, 1997, 2002, 2003 and 2005 for all trees. In addition, height was recorded all trees in 2002 and 2003 including social position of trees in 2005. At Khotokha, dbh and height data were recorded in 2000, 2004, and 2007 and social position, respectively.

Taba

The trial design is a completely randomized design with four treatments in three replicates Treatments were: i) thinning of dead, dying and suppressed trees (low thinning), ii) thinning to achieve 3x3m spacing, iii) thinning to achieve 4x4m spacing and iv) control. Plot measurements were done in 1988/89, 1991 and 1997 including dbh. Trees were enumerated in 1cm dbh class and tree heights measured in 1997 and summarized in 1-5 cm dbh classes. Data measurement continues. Initial tree height and removed stems data do not exists.

Data analysis

Hurchi and Khotokha

As both experiments lacked replications, no inferential statistical methods could be used for analysis. Results are merely descriptive. We compared stem density, basal area, periodic volume increment, standing volume, dbh class distribution, mean dbh and cumulative total production between

different thinning treatments. Stand volume were derived from local volume table for Blue Pine developed for Bumthang by (Bürgi, 1991).
Volume = $0.0001521*dbh^{2.520318}$

We calculated increment by dividing the volume between two subsequent measurements by the number of vegetation periods in between them. Stand stability was assessed using slenderness coefficient (SC) = height (cm)/dbh (cm). Trees with SC > 100 were categorized as unstable, 80-100 as critical and <80 as stable (Rosset and Rinchen, 1999).

Taba

We used stem density and stand volume/ha data compiled by Desmond and Norbu (1998) for the analysis. An analysis of covariance (ANCOVA) was performed to test whether thinning treatments significantly affected growth parameters or not. We included initial values from the first recording done in 1991 as covariates to filter out the effects of initial differences in stand parameters. We tested differences between treatments in stem density and stand volume and used LSD post-hoc tests to identify group differences.

RESULTS

Stem density of remaining and removed stems

At Hurchi, the initial stem density was 1000 stems/ha in the control plot compared to treated plots. During the first thinning in 1988, the stem density was reduced by 50% and 25% in heavy and moderate plots, respectively. Subsequent measurement done in 1991 showed quick recovery in stems/ha in moderate plots but slow in heavy plots. Control plot stems/ha was highest in 1991 and thereafter declined due to mortality until 2005 and equals with moderate plots (Fig. 1A). At Khotokha, stem density in all the treatments was high during the start but afterwards it declined irrespective of treatment (Fig. 1B).

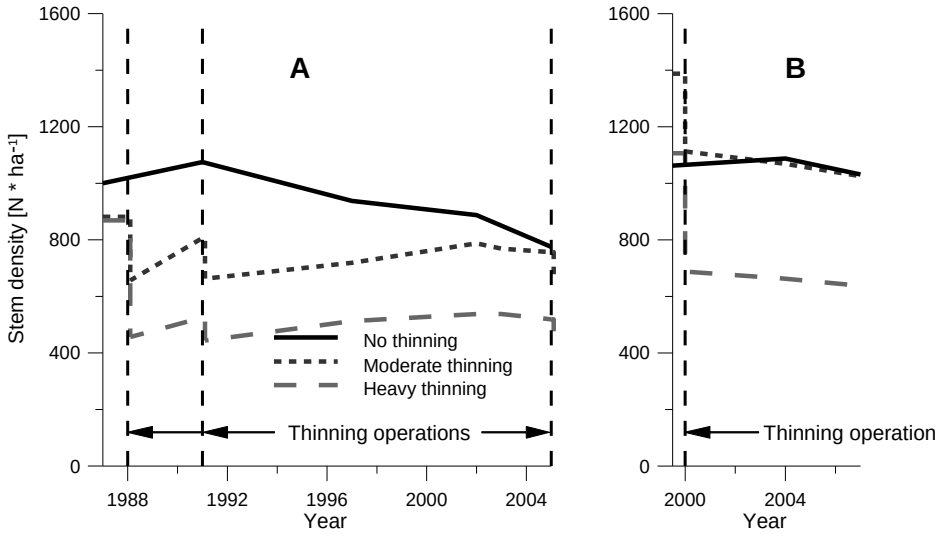

Fig. 1. Stem density under different thinning treatments in Hurchi (A) and Khotokha (B)

At Taba, there were 1000, 1824, 1906, and 2066 stems/ha in 4x4, 3x3, low thinning and control plots, respectively. Stems/ha differed significantly between treatments from initial stem density in 1988 (N88; see Table 2). Table 2 shows that there was significant difference between thinning intensities ($P < 0.05$). The LSD multiple range test confirmed that stem density in 4x4 m differed significantly from others (Table 3).

Table 2. Stems/ha in thinning treatments in 1997 at Taba

Source	SS	DF	MS	F	P-value
Covariates					
N88	15412	1	15412	5.38	0.053
Main effects					
Treatment	49036	3	16345	5.71	0.026*
Residual	20037	7	2862		
Total	75821	11			

Table 3. Multiple range test for Table 2

Treatment	Count	LS Mean	LS Sigma	Homogenous group
4x4	3	160.10	31.32	a
3x3	3	291.80	31.13	b
Dead&dying	3	304.95	31.23	b
Control	3	330.52	33.75	b

Different letters show significant differences at $p \leq 0.05$

At Hurchi, initial dbh was highest in heavy plot, while in other two treatments had comparable dbh of 16.3cm and 16.2cm, respectively (Fig. 2A). First thinning shifted the mean dbh in heavy plots from 17.3cm to 19cm. Mean dbh increased in all treatments from 22.7cm to 23cm in 2005. Removal of competitors in the moderate plot in 2005 lead to reduction of dbh in both treatments (Fig. 2A). Mean dbh of standing trees at Khotokha was comparable in three treatments at the start but in 2007 it increased to 18.2cm, 17.4cm, and 17.3cm in heavy, moderate and control plots, respectively. Thinning in 2000 did not shift dbh in either treatment (Fig. 2B).

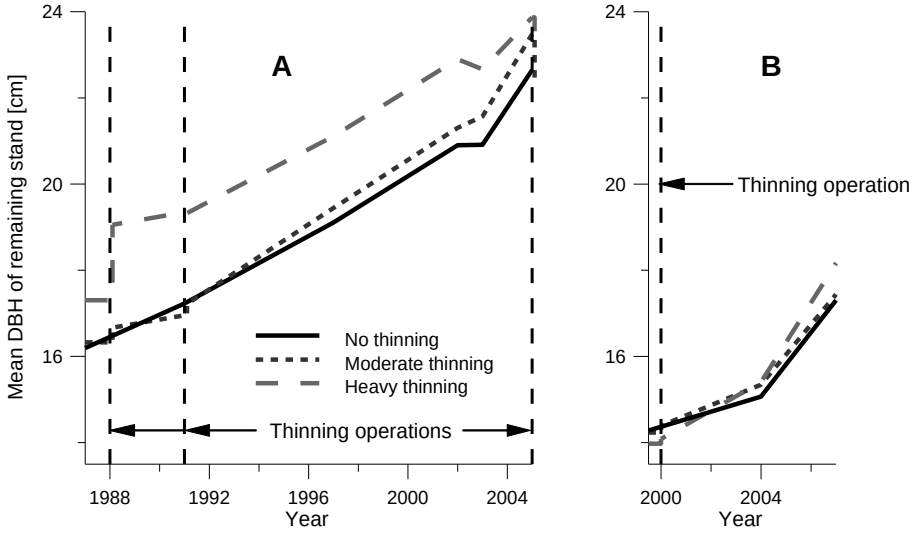

Fig. 2. Mean dbh under thinning treatments at Hurchi (A) and Khotokha (B)

Mean dbh of the removed stems at Hurchi was 15cm for both treatments in 1988, but 16cm in moderate and 19cm in heavy plots in 1991. In 2005, dbh attained 31cm in moderate and 32cm in heavy plots, respectively.

Table 4. Mean dbh of removed stems in thinning treatments at Hurchi and Khotokha

	Hurchi				Khotokha			
Mean dbh of removed stand	Year	moderate	heavy	control	Year	moderate	heavy	control
	1988	15	15	n.a.	2000	14	14	n.a.
	1991	16	19					
	2005	31	32					

Annual increment

Between the first and second thinning entries, mean annual increment/ha was lowest in the heavy plots at Hurchi and Khotokha. After the second cut, heavy plots surpassed the mean annual increment of the control plot at Hurchi, while it still remained lowest at Khotokha. Mean annual increment/ha was highest in the moderate plots (Table 5).

Table 5. Annual increment and basal area in different thinning treatments at Hurchi and Khotokha

	Hurchi				Khotokha			
Annual	Year	moderate	heavy	control	Year	moderate	heavy	control
increment	1988-91	14.61	10.96	19.25	2000-04	9.22	7.25	8.14
[m^3/year]	1991-97	16.65	15.10	10.89	2004-07	15.92	13.88	15.71
	1997-02	21.09	16.68	17.28				
	2002-03	4.26	-4.26	-11.59	n.a			
	2003-05	27.37	11.82	15.01				
Basal area	1988	21.33	23.10	23.85	2000	22.87	18.03	17.84
[m^2/ha]	1991	21.17	17.73	29.24	2004	20.51	13.25	20.41
	1997	25.06	21.04	31.59	2007	25.53	17.79	25.61
	2002	33.39	26.68	36.53				
	2003	33.63	26.34	34.87	n.a			
	2005	39.19	28.12	37.31				

Basal area, volume and mortality

Initial basal area in the moderate plot at Hurchi was lower and higher at Khotokha compared to other treatments. Due to strong initial reduction, basal area remained lowest in the heavy plots throughout observation period. By the time of final cut, basal area in moderate plots surpassed that of the control plots at Hurchi and reached at par with Khotokha (Table 5). Stand volume at Hurchi was comparable between control and heavy plots (227m^3/ha versus 220m^3/ha, respectively) while moderate plot had 204 m^3/ha. After first cut in 1988, stand volume in heavy plot reduced to 144m^3/ha while in moderate plot it reduced to 153m^3/ha. The control plot had the highest stand volume until 2004 but peaked at 425 m^3/ha in 2005. The moderate plot showed rapid increase in stand volume than control plot (457m^3/ha) in 2005 (Table 6; Fig. 3). At Khotokha, moderate, heavy and control plot had stand volume of 182m^3/ha, 146m^3/ha and 144m^3/ha, respectively. At Taba, stand volume did not significantly differ between treatments, when considering the initial stand volume in 1988 (V88) as covariate but significantly affected volume in 1997 (Table 7). Stand volume in 4x4 spacing was significantly lower than control plots.

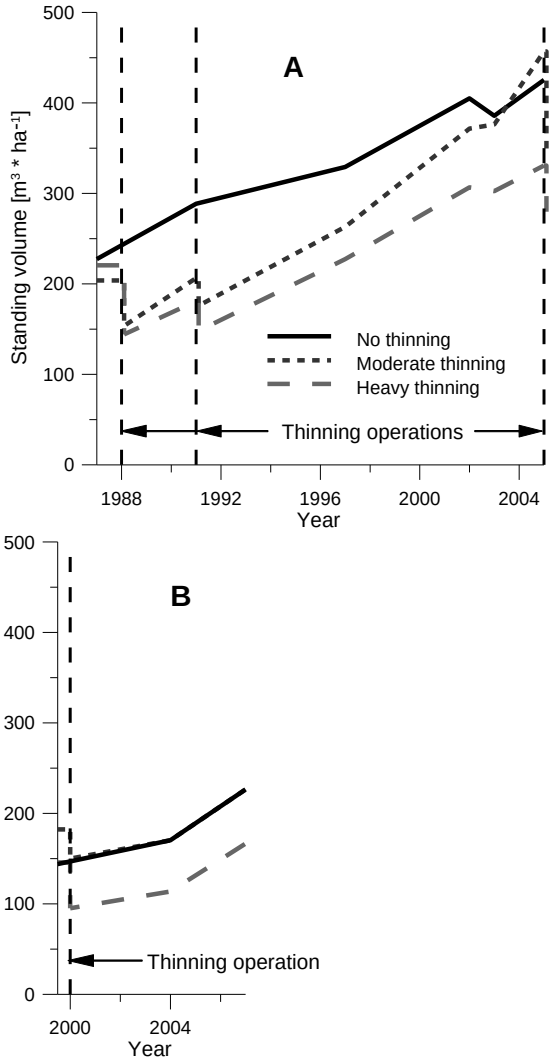

Fig. 3. Stand volume in different thinning treatments at Hurchi (A) and Khotokha (B)

Table 6. Stand volume, in growth and mortality by treatments and year at Hurchi and Khotokha

	Hurchi				Khotokha			
Standing	Year	moderate	heavy	control	Year	moderate	heavy	control
volume	1988	203.76	220.50	227.30	2000	182.22	145.71	143.95
[m^3/ha]	1991	206.40	180.87	288.53	2004	170.22	113.62	169.90
	1997	263.01	227.31	329.17	2007	226	166.60	229.78
	2002	371.57	306.69	405.03				
	2003	376.18	302.47	385.79				
	2005	456.82	330.78	425.41				
Volume cut [m^3/ha]								
1. thinning	1988	50.3	76.3	0	2000	32.2	50.6	0
2. thinning	1991	30.5	32.8	0	n.a.			
3. thinning	2005	112.7	51.0	0				
Total	88-05	193.4	160.1	0	00-07	32.2	50.6	0
In-growth	88-91	9.8	4.3	3.2	n.a.			
[m^3/ha]	91-97	4.1	0	0.3				
	97-02	4.1	0	1.0				
	02-03	0.7	0.3	0				
	03-05	0	0	0				
Total	88-05	18.7						
Net volume [m^3/ha]	88-05	273.05	201.59	189.14	00-07	145.75	151.72	159.63
Mortality	88-91	0.7	0.5	0	00-04	6.9	3.9	0
[m^3]	91-97	0.3	1.6	14.4	04-07	5.7	2.2	1.8
	97-02	0.4	6.0	8.3				
	02-03	1.3	0.3	3.8				
	03-05	1.5	6.4	5.9				
Total	88-05	4.2	14.8	32.4	00-07	12.6	6.1	1.8
Total volume [m^3/ha]	88-05	275.41	208.26	203.41	00-07	271.24	223.26	231.56

Table 7. ANCOVA of thinning treatments on stand volume in 1997 at Taba

Source	SS	df	MS	F-ratio	P-value
Covariates					
V88	11409	1	11409	24	0.001
Main effects					
A: treatment	1482	3	494	1.06	0.423^{ns}
Residual	3254	7	465		
Total	19355	11			

Volume cut in the first two thinning were highest in heavy plot at Hurchi. In the third thinning, volume cut was higher in the moderate plot. The cumulative cut volume was also high in the moderate plot. At Khotokha, cut volume was 50% high in the heavy plot compared to the moderate

plots (Table 6). Cumulative total volume was comparable between heavy and control plots but the latter plots had high mortality (Figure 4). At Khotokha, total volume was comparable between treatments. Mortality was minimal in all treatments.

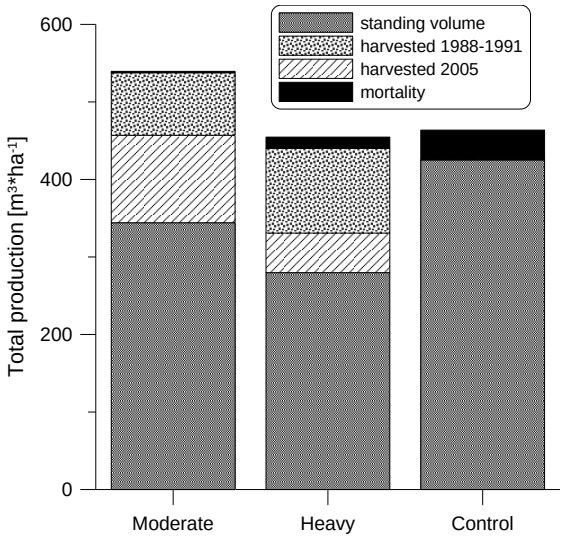

Fig. 4. Gross volume at Hurchi in three different treatment

Ar Hurchi, total volume accumulated in moderate plots reached 275% of the initial stand volume. In the heavy and control plot, it was 208% and 203%, respectively.

Stand stability and dbh class distribution

Thinning reduced slenderness coefficients of trees at Hurchi. Slenderness coefficients in different thinning intensities are shown in Table 8.

Table 8. Slenderness category by dbh class in different treatments

Treatment	Stable	Critical	Unstable
Heavy	dbh >33 cm	dbh 23-28 cm	dbh <18 cm
Moderate	dbh >38 cm	dbh 23-33 cm	dbh <18 cm
Control	dbh >38 cm	dbh 28-33 cm	dbh <23 cm

Slenderness coefficients showed 15%, 9% and 6% of trees stable in heavy, moderate and control plot, respectively. The control plot had the highest ratio of unstable trees (71%) followed by moderate (65%) and heavy (55%). Thinning affected dbh class distribution of the remaining

stand at Hurchi (Fig. 4). Both heavy and moderate plots had concentration of stems in dbh size class (>28 cm), but this effect was stronger in heavy plot. While a reverse-J curve is indicative of continuous recruitment was still obvious in moderate plot, though the number of stems did not appear different in small and large size classes in heavy plots.

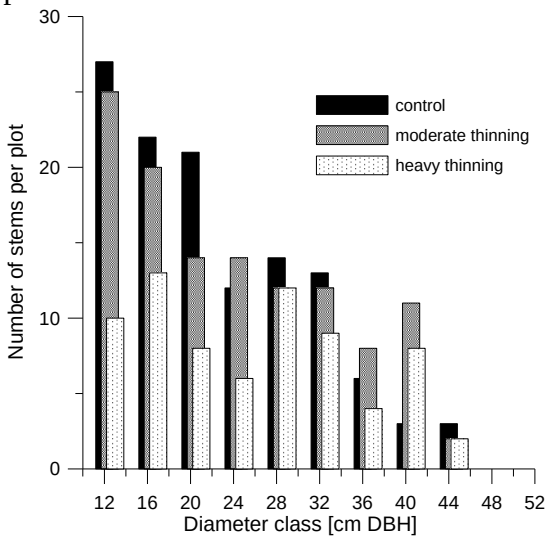

Fig. 4. Dbh class distribution in different treatments at Hurchi

DISCUSSION

Dbh, stand density, increment and economic considerations

Heavy thinning at Hurchi resulted in reduction of stem density to 400 stems/ha, which did not allow recovery after the initial thinning. Conversely, gradual reduction of stem density in moderate plot allowed continuous recruitment. Limited mortality in control plot make stems congestion, which indicates necessity for thinning at regular entries. In the control plot, stem density declined from 1991 onwards due to increasing mortality resulting from competitive exclusion of stems. At Khotokha, all treatments showed stable to critical indicative of stand initiation stage. Natural mortality occurred inter alia thinning. At Taba, heavy thinning led to significantly lower stems/ha compared to other plots indicating excessive removal of stems. The increase of mean dbh in 1988/1991 thinning operations at Hurchi indicates low thinning while decrease in dbh in 2005 shows matured stand requiring high or selection thinning. The initial strong increase of dbh in heavy plot resulted from excessive removal of small-size understory and suppressed trees and thus

growth concentrated on a few large individuals which changed dbh structure (Brockley, 2005). The short observation period at Khotokha did not allow differentiation between treatments. Mean dbh of trees cut in first thinning was identical for both treatments and not of commercial size indicative of pre-commercial thinning. Nevertheless, many trees in the first thinning reached the commercial size of 16 cm dbh. In the second thinning, mean dbh in moderate plot remained similar initial thinning while in heavy plot commercial size was attainable. Mean dbh in both treatments was above the commercial size in third thinning indicating that thinned stems is marketable to earn revenue (Rosset and Rinchen, 1997). According to Rosset (1997) thinning operations in bluepine crosses the profit margin above 13cm dbh and therefore even the first "pre-commercial" thinning entries can be cost-neutral.

Stand volume and mortality

Even though individual tree growth rates did not differ (data not presented), mean annual increment on the stand level was more than double in moderate plots at Hurchi compared to heavy plots. Excessive removal of trees in the first thinning led to sub-optimal stand volume in heavy plots. Yield capacity of the stand could not reach at optimum level. The Moderate plot surpassed the stand volume of the control plot by 2003 indicating that thinning leads to better stand utilization to grow. Similar increase of volume in low and moderate plots compared to heavy plots was reported by (Baldwin et al. 2000). Mortality was highest in control plots confirming that competitive exclusion resulting in stand volume losses prevented by thinning (Johnstone, 2005; Mäkinen and Isomäki, 2004a), contingent upon thinning after stand initiation stages especially on sites with high stems/ha (Mäkinen and Isomäki, 2004b). High mortality in heavy plots from snow damages resulted lower stand stability due to excessive removal of stems opening up of canopy (Rinchen et al., 1998). The cumulative stand volume, volume cut during thinning and mortality showed that moderate thinning utilizes stand yield capacity at optimum level. Heavy and control plots did not differ, however, mortality was high in the control plot arriving at the conclusion that no thinning invites damages from competitive exclusion of stems and snowfalls. At Taba, significantly high stand volume in control plots compared to other treatments arises from short observation period between 1991 and 1997 (Desmond and Norbu, 1998). Similarly, stand volume at Hurchi was higher in control plots compared to moderate plot

for 15 years after first, as thinning results are not expected before 10 years after treatment (Johnstone, 2005).

Stand stability and dbh class distribution

Thinning affected stand stability through reduction of individual tree slenderness. Increased thinning intensity resulted in lower slenderness coefficients indicative of increasing tree stability (Mäkinen and Isomäki, 2004a). Reduction in slenderness leads to tapering increasing bole resistance to physical stresses such as wind and snow (Cucchi and Bert, 2003). A strong slenderness reduction is expected within the first 5 years' after thinning (Johnstone, 2005), however, strongly depends on the onset of thinning during stand development (Mäkinen and Isomäki 2004a). Hale et al (2004) reported that opening up of the canopy lead to decreased stand stability, heavy snow damage in heavy plot at Hurchi in March 1998 (Rinchen et al., 1998) wind damage subsequently. Heavy thinning eliminated a large number of small-size trees and thus affected stand structure and recruitment by changing the reverse-J dbh distribution to an even pattern indicative of lower capacity for continuous recruitment. In other cases, repeated thinning entries resulted in unimodal dbh distribution (Brockley, 2005; Johnstone, 2005; Mäkinen and Isomäki 2004a). In spite of strong opening up of the canopy in heavy thinning, pre-commercial thinning operations do not usually initiate new seedling recruitment (Homyack et al., 2004) due to rapid crown closure.

General considerations

Present studies do not yield conclusive evidence on optimal frequency of thinning operations (Tenzin, 2001). However, periodic growth rates indicated that more frequent, moderate thinning entries positively affect stand productivity and stability. Intensity and frequency of thinning operations has to be determined based on silvicultural objectives, which in turn depends on site and stand conditions, age, stocking, vulnerability to snow and wind damage and economics.

CONCLUSION AND RECOMMENDATION

The results of three thinning trials in western and central Bhutan indicates that

- Moderate thinning leads to better stand structure with increased volume and stability of the standing trees.

- Mortality loss due to competitive stem exclusion is minimized through periodic thinning
- Heavy thinning optimizes stability and growth of individual trees but compromises stand stability and volume increment due to reduction of stem density. It is recommended that thinning be carried out at every 10 years' interval from the onset of stand closure.
- Thinning intensity be moderate and removal should not exceed 25% of the standing volume or basal area.
- Do not merely concentrate on removal of malformed and damaged trees but try to favor promising individuals by removing their immediate competitors.
- Maintain focus on a well structured stand and do not create large gaps in the canopy.

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Influence of slope-aspect on the species composition and structural traits along the altitudinal gradients of the inner dry valleys.

Pema Wangda[1], Dorji Gyaltshen[1], Tshewang Norbu[1]

ABSTRACT

Forest types along north and south facing slopes of a typical dry valley in the western Bhutan Himalaya was studied to clarify the species richness and forest structure. Based on the analysis of quantitative vegetation data, environmental attributes and physical observation during the field study, the different forest types were depicted along the same altitude but in different aspect. A total of thirty four tree species were recorded comprising of three life-forms viz. evergreen broad-leaved, deciduous broad-leaved and evergreen needle-leaved conifers respectively. Evergreen broad-leaved and deciduous broad-leaved trees were concentrated towards the north facing slopes while all three conifers (Pinus roxburghii, Pinus wallichiana & Pinus bhutanica) *were found towards the south facing slopes. Higher species number (26) was recorded along the north facing slope and lower species number (19) was recorded on the south slope. Structurally, the trees attain an average height of 27.2 m on the north facing slope while it is only 17.0 m along the south facing slope. The upper limit of* Pinus roxburghii *was found at 2380 m along the south facing slope while it is only at 1780 m along the north facing slopes. The difference in forest diversity, structures and distribution limit on the two slopes were clarified using environmental factors of soil moisture content, relative air humidity, soil compaction and air temperature which were found to be the controlling factors. High soil moisture content (20 %), low temperature and low soil compaction leads to high floristic diversity along the north facing slopes while lower soil moisture content (10 %) and high soil compaction together with high temperature favors conifer and xeric type of species. South facing slope showed fragile forest ecosystem while north facing slopes showed stable, diverse forest ecosystem. Therefore, the management of the forest resources should be planned carefully using the scientific findings of the research for a sustainable utilization of the natural resources.*

[1] RNR-RDC-Yusipang

KEY WORDS: Soil Moisture Content, Relative Humidity, Soil hardness, Temperature, Structural Traits

INTRODUCTION

The flat lands are limited only towards the river valleys in the mountainous country like Bhutan. Series of mountain systems stretches along the north-south and from east to west direction (Wangda et. al 2009b). The dry valleys are prominent in the middle reaches of big rivers extending from south to north dissecting the mid mountains between southern mid Himalaya and northern greater Himalaya (Ohsawa 1987a, Eguchi 1997, Wangda & Ohsawa 2006a). Accordingly, the vegetation distribution patterns along these dry valley slopes showed that ridges or mountain tops are wetter than the lower slopes due to subsidence over valleys in the slope wind circulation (Wangda et. al 2009). Similarly, the vegetation distribution differs significantly along the north and south facing slopes at the same altitude.

The slope-aspect factor plays an important role in the vegetation distribution of the mountainous country. One prominent example of the slope-aspect influence was observed along Dochula-Lobesa slope series. Similar vegetation patterns influenced by slope-aspects are found all over Bhutan (Personnel observation). In an extreme case, dry, steep south facing slopes were almost devoid of tree growth while north facing slopes were covered with trees (e.g. Ridge opposite to Khasadrupchu hydel) while at the higher altitude, the south facing slopes were covered with conifers and north facing slopes with deciduous broad-leaved trees (e.g. Ridge opposite to Gangtey Lhakhang) (Personnel observation 2009, Photo 2). Similar forest types are mostly found along the slopes of the mid-altitude inner dry valleys of the Bhutan Himalaya.

Similar observations of slope-aspect influence on vegetation change were studied widely around the world (Bennie et. al 2006, Wilkinson & Humphreys 2005, Bochet & Garcia-Fayos 2004, Canton et. al 2003, Sternberg & Shoshany 2001).

Based on the ocular observation, the field work was conducted to clarify the factors leading to distinct vegetation composition and structural traits along the north and south facing slopes.

Objectives

This study aims to clarify the influence of slope-aspect on the above ground vegetation mainly trees and shrubs. Specifically, the study was initiated with the following objectives:

1. Clarify the environmental conditions along south and north facing slopes of the study area,
2. Compare vegetation composition and structural changes of south and north facing slopes and
3. Clarify the environmental factors causing the changes along the same altitude but along different slope-aspect.

MATERIALS AND METHODS

Study area

Climatically, the study area falls in one of the typical dry valleys of the Bhutan Himalaya (Wangda & Ohsawa 2006a) along the eastern slope of Dochula facing Punatsangchu in western Bhutan (Fig. 1A, B). The study was conducted in two sites along the same altitudinal gradient but in different aspect and slope (Fig. 1B). The study sites were along the Dochula-Lobesa series of north (Menchuna-Thinlaygang series) and south facing slopes of Nahi-Hesithangkha series (Fig. 1B).

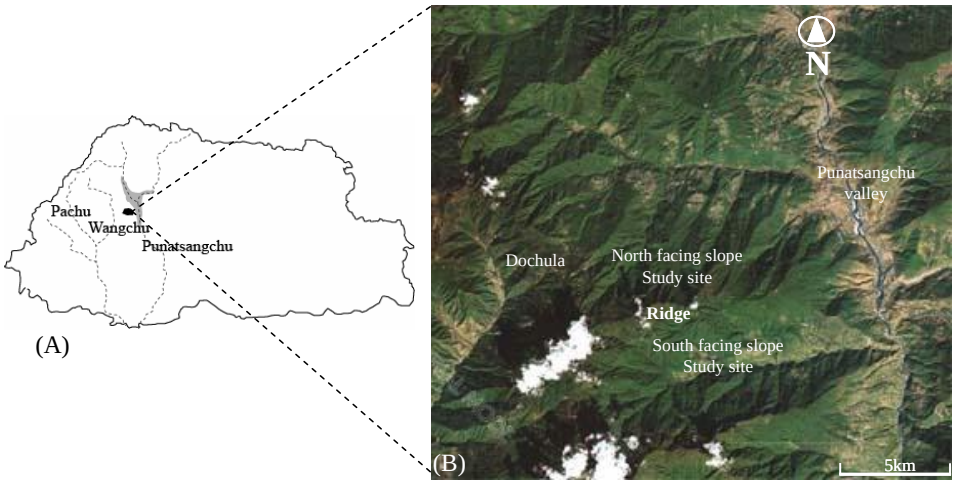

Fig. 1. Map of the study area; (A) Map of Bhutan showing the study area and, (B) satellite image of the study area indicating north and south facing slopes of the study area.

Environmental data collection

Soil moisture content, air relative humidity, air temperature and soil hardness were measured along the altitudinal gradients form 2680 m a.s.l. with an altitudinal interval of 100 m to 1380 m a.s.l. at the valley bottom on both sides of the slope.

Soil moisture content was measured by HydroSense (CD 620+CS 620) (CAMPBELL SCIENTIFIC INC. Logan, Utah) bearing 12 and 20 cm probes during the field survey from 20-26 January 2010. Similarly, soil hardness was measured by push cone (Yamanaka's soil hardness tester, Kiya Seisakusho Ltd. Tokyo). The relative humidity and air temperature was measured by VAISALA (made in Finland) instrument.

Vegetation survey

Maximum tree height, maximum diameter at breast height and floristic composition were recorded at every 100 m altitude interval from 2680 m a.s.l. to 1380 m a.s.l. on both sides of the slope (study area). We used digital hypsometer having transponder for recording the tree height and similarly diameter tape was used to measure the diameter of a tree. All the species within 10 meter circumference were identified and recorded. The altitude was measured by both digital altimeter and manual (Sunto) altimeter.

Nomenclature of plants followed after Flora of Bhutan Grierson and Long, 1983, 1984, 1987, 1991, 2001; Noltie, 1994, 1999, 2000). Wild Rhododendrons of Bhutan (Pradhan, 1998), Flowers of the Himalaya: A supplement (Stainton, 1988), Flowers of the Himalaya (Polunin & Stainton, 1984), and Photo-album of plants of Eastern Himalaya (Hara, 1968).

Vegetation data analysis

The preliminary data was processed using pivotal table of the Microsoft Excel. Graphs are drawn by Microsoft excel and illustrator.

RESULTS

Environmental conditions: *Soil moisture content (%), soil hardness (kg/cm^2), relative humidity (%) and air temperature (^{o}C).*

Environmental conditions of soil moisture content and soil hardness were measured along the north and south facing slopes of the study area (Fig.

2A, B). Soil moisture content (%) measured at 12 cm and 20 cm soil depths which gives similar soil moisture content at two different depths showed clear difference in soil moisture content along north and south facing slopes (Fig. 2 A). Soil moisture content decreased significantly along the north facing slope than along the south facing slopes as represented by the steep slope (North) when compared to the gentle south facing slope (Fig. 2A). The difference in soil moisture content was found significant at the higher altitude than at the lower altitude as represented by the widening gap of the two trend lines. The trend lines taper at the lower altitude which signifies low soil moisture content in the pine forest below 1600 m a.s.l. (Fig. 2 A). The soil moisture content along the south facing slope was found relatively low and decreased slowly along the decreasing altitude compared to north facing slope (Fig. 2A).

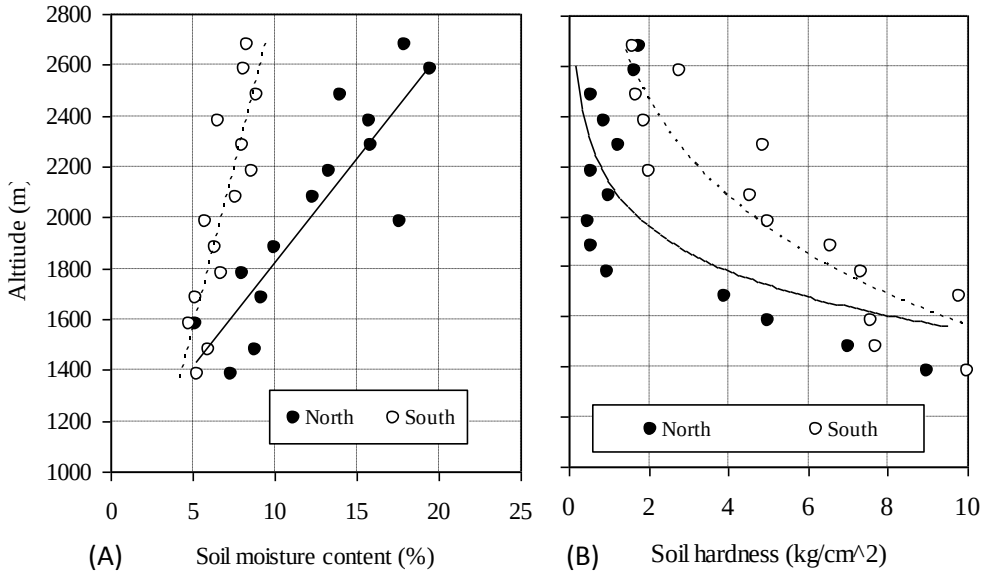

Fig. 2. Environmental conditions along north-south aspect of the study area; (A) Soil moisture content (%) and (B) soil hardness (kg/cm^2) altitudinal gradient from 2680 m a.s.l. to 1380 m a.s.l.

Soil compaction was measured as soil hardness in kg/cm^2 using soil hardness tester called push cone. The result showed soil compaction was prominent along the southern slope compared to the northern slopes (Fig. 2B). The soil hardness was found increasing along the decreasing altitude

on both aspect of the slope. At the lower altitude the soil hardness was found to be similar while at the mid altitude the difference in soil hardness was found wider and again tends to taper at the higher altitude (Fig. 2B). This trend was presented by the tapering of the curve at the higher and lower altitudes in the broad-leaved forest and pine forest zones (Fig. 2B).

Similarly, instantaneous measurement of both relative air humidity and air temperature recorded during the observation period revealed similar trend with that of soil moisture content (Fig. 2 & 3). The data showed north facing slope has higher air relative humidity compared to the south facing slope. The higher and lower altitude showed similar trend of air relative humidity (Fig. 3 A). Recorded air relative humidity showed significantly higher at the mid altitudes probably because of the cloud zone around 2000-2500 m a.s.l. as clarified by Wangda 2006. While relatively low at high altitude and very low at the lower altitude (Fig. 3 A).

On the contrary, instantaneous air temperature recorded revealed higher temperature along the south facing slopes compared to the north facing slopes (Fig. 3 B). Thus, the south facing slopes showed high temperature but low air humidity leading to extreme environmental conditions.

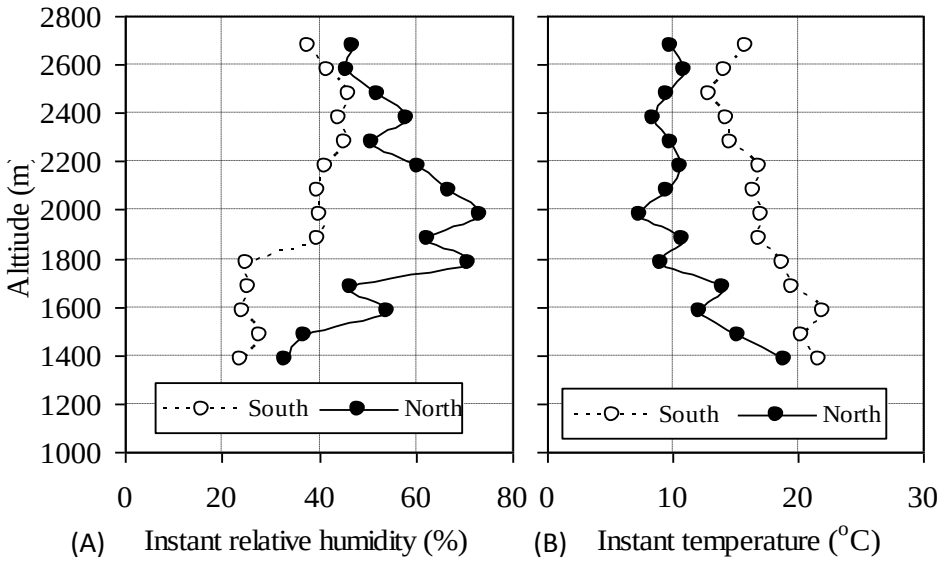

Fig. 3. (A) Instantaneous relative humidity (measured during the observation at different time) and (B) Instantaneous air temperature

measured during the observation period along different aspects of the altitudinal gradient from 2680 m a.s.l. to 1380 m a.s.l.

Floristic composition

A total of thirty four (34) species above ground vegetation composed of three (3) conifers, ten (10) evergreen broad-leaved trees, nine (9) evergreen broad-leaved shrubs, six (6) deciduous broad-leaved trees and six (6) deciduous broad-leaved shrubs were recorded (Tab. 1). All three species of conifers were recorded along the south facing slopes while only *Pinus roxburghii* was recorded at the lower altitudes of the north facing slope. Along the south facing slope, *Pinus roxburghii* reached up to 2380 m a.s.l. while the upper limit of the same species was recorded at 1780 m a.s.l. along the north facing slope (Tab. 1). Most of the evergreen board-leaved trees were recorded along the north facing slopes. Similarly, evergreen broad-leaved shrubs and deciduous broad-leaved trees and shrubs were also found on the north facing slopes. However, xeric species particularly shrubs are found on the south facing slopes (*Berberis aristata, Viburnum cylindricum, Desmodium* sp., *Innula* sp., *Phyllanthus* sp., *Rosa* sp., *Rubus* sp.,).

Higher numbers of *Quercus* species were record along the north compared to south facing slope. There were six oak species recorded along the north facing slope while only four oak species were found on the south facing slope (Tab. 1). Most of the evergreen broad-leaved trees and deciduous broad-leaved shrubs were recorded from the north facing slopes.

Tab. 1: Comparison of floristic composition along the north and south facing slopes of the study area

MEASURING POINTS (Along the altitude)														
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14
Altitude (m)	1380	1480	1580	1680	1780	1880	1980	2080	2180	2280	2380	2480	2580	2680
Max ht. (m)	29.0	27.5	33.1	37.0	20.2	21.9	23.2	25.0	25.0	15.5	40.0	27.6	30.0	29.0
Max. DBH (cm)	44.5	49.0	56.3	59.0	31.0	47.5	77.0	45.0	45.0	72.0	100.0	70.0	87.0	72.0
CONIFEROUS TREES														
Pinus roxburgii	NS	NS	NS	NS	NS	S	S	S	S	S	S			
Pinus wallichiana												S	S	
Pinus bhutanica														S
EVERGREEN BROAD-LEAVED TREES														
Quercus lanata			N	N					S	S	S	NS	NS	S
Quercus glauca			N	N	N	N								
Rapanea capitellata			N	N	N	N						S		
Rhododendron arboreum					N	N	N	N	N	NS	NS	NS	NS	NS
Castanopsis sp.						N	N	N	N	N	N	N		
Myrica esculenta								N	N					
Michelia velutonia									N					
Quercus oxydon											N	N	N	N
Quercus thomsoniana												N		
Quercus semecarpifolia													N	NS
EVERGREEN BROAD-LEAVED SHRUBS														
Berberis aristata	N	N	NS	NS	NS	S	S	S	S	S	S	S	S	
Viburnum cylindricum				N	N	N		S	S	S	S	S	S	S
Myrsine semiserrata					N	N	N	N	N	N	N	N	S	S
Daphne bholua						N	N	N	N	N	N	N	N	N
Eurya acuminata						N	N	N	N	N	N	NS	NS	NS
Symplocos sp.										N	N	N	N	N
Ilex dipyrena										N	N	N	N	N
Gaultheria fragrantissima												S	S	S
Illicium griffithii													N	N
DECIDUOUS TREES														
Lyonia ovalifolia				N	N	N	N	NS	NS	NS	NS	NS	NS	NS
Quercus griffithii				N	N	N	N	N	N	N	N	N		
Schima wallichii				N	N	N								
Betula alnoides									N					
Acer sp.												N	N	N
Corylus faginea													N	
DECIDUOUS SHRUBS														
Desmodiumn sp.	S	NS	NS	S	S									
Innula cappa				S	S	S	S	S	S					
Phyllanthus urinaria					S	S	S	S	S	S				
Rosa sericea						S	S	S	S					
Rubus ellipticus										S	S	S	S	S
Elaegnus parvifloia											S	S	S	S

Note: **N** refers to the species present along the north aspect and **S** refers to the species present along the south aspect. **NS** refers to the species present in both aspects

Species richness

Species richness differs significantly along north and south facing slopes (Fig. 4). The difference was found significant at the mid altitudes (1800-2000 m) than at the high and low altitude (Fig. 4). South facing slope showed relatively low number of species compared to the north facing slopes along the altitudinal range from 2680-1380 m a.s.l., (Fig. 4). At the higher altitude, both slopes showed relatively higher number of species and similarly, at the lower altitude both revealed lower number of species. However, north facing slope revealed higher number of species than the south facing slopes.

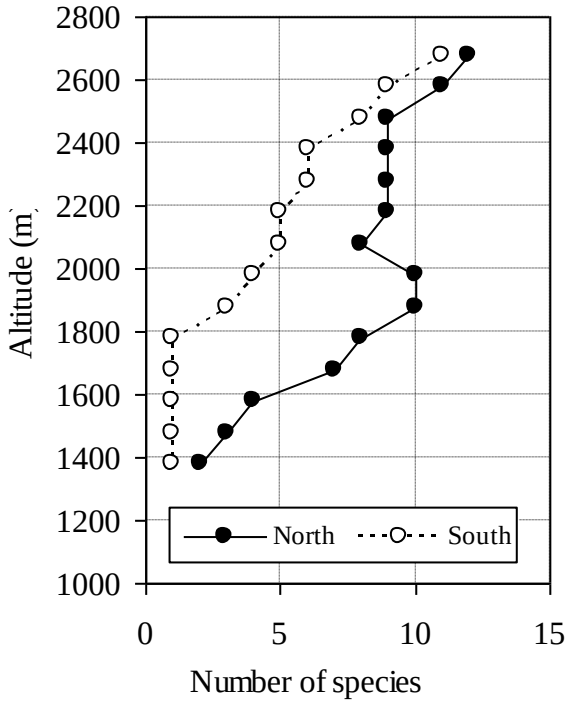

Fig. 4. Number of species counted within 10 m radius observation points during the field survey along north and south facing slopes from 2680 m a.s.l. to 1380 m a.s.l.

Forest structural features

Forest structural traits of maximum height and maximum diameter at breast heights were measured and recorded along the observation points on both aspects (Fig. 5 A, B). Both height and diameter revealed similar

trends of changes along the altitudinal gradients on both aspects (Fig. 5 A, B). However, the north facing slope showed comparatively larger structures than the south facing slopes. The dominant trees represented by tall trees and larger diameter were found at the higher altitudes on both aspect. On the other hand, shorter heights with thinner diameter trees were found at the lower drier sites mainly pine trees (Fig. 5 A, B, Tab. 1). The tallest tree was found to be 40 m attained by *Quercus griffithii* at 2380 m a.s.l. along the north facing slope while the tallest tree found on the south slope was only 25.7 m attained by *Pinus roxburghii* at 1980 m a.s.l. (Tab. 1, Fig. 5 A). Similarly, the maximum diameter at breast height was recorded 100 cm attained by the *Q. griffithii* while maximum diameter at breast height of 74.5 cm was attained by *Q. lanata* at 2680 m a.s.l. on the south facing slope (Fig. 5 B).

However, the mid-altitudes of both north and south facing slopes showed similar trend of forest structures (height and diameter) as represented by Figure 5 A & B.

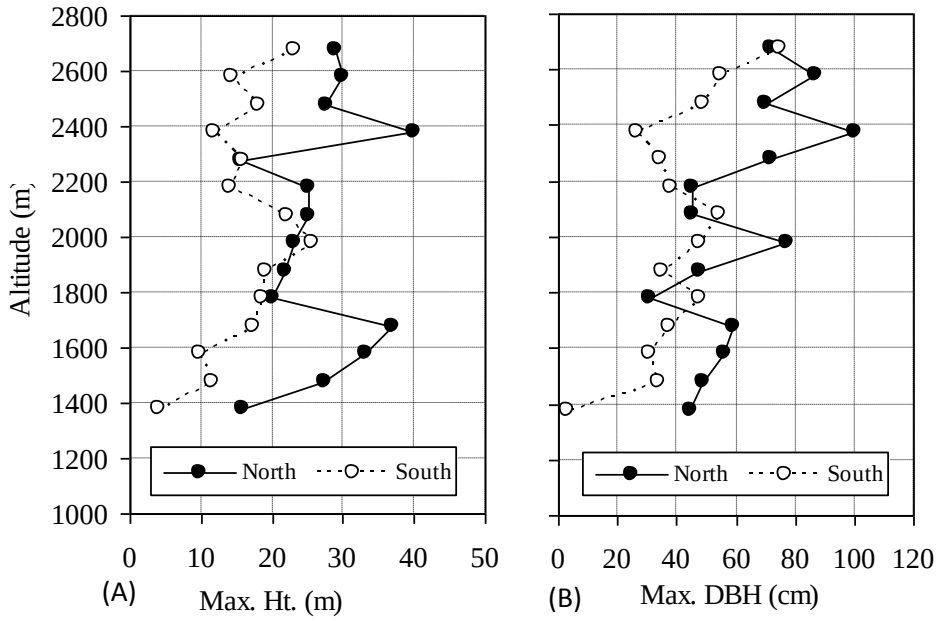

Fig. 5. Forest structural features along the altitudinal gradients of the study area. (A) Maximum tree height (m) and (B) maximum diameter height (cm) measured within 10 m radius observation point along different aspects of the altitudinal gradient from 2680 m a.s.l. to 1380 m a.s.l.

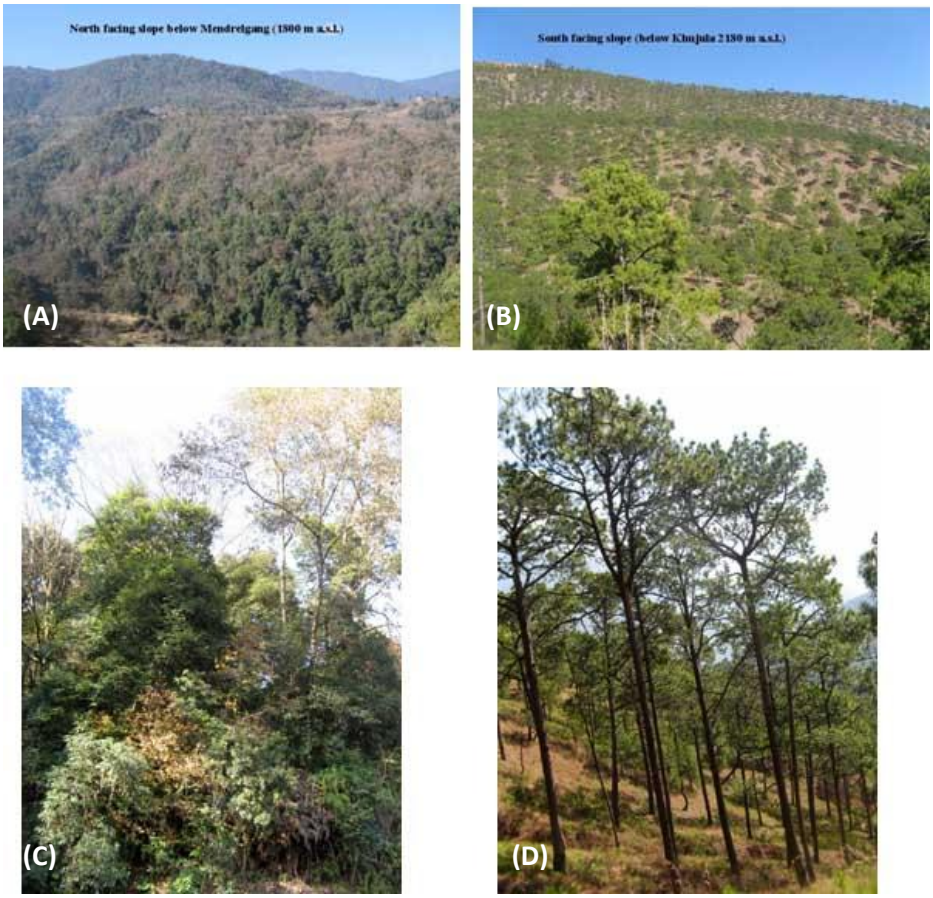

Photo 1. Comparison of forest composition along the (A) North facing slopes (Below Mendigang; c. 2000 m a.s.l.) and (B) South facing slopes (Below Khujula; c. 2100 m a.sl.) of the study area. (C) Mixed broad-leaved forest at Lumitsawa (2000 m a.s.l.) and (D) Chir pine forest below Khujula (2000 m a.s.l.)

CONCLUSION

The influence of slope-aspect on vegetation distribution pattern and structural changes were partly explained by the environmental factors of soil moisture content, air relative humidity and soil compactions (Photo 2). The high soil moisture content and relatively lower air temperature of the north facing slopes favoured broad-leaved species to occur while south facing slopes with low soil moisture conditions and relatively high air temperature favours xeric type of species such as conifers (*Pinus roxburghii*) and deciduous shrubs (*Desmodium, Rubus, Rosa*). Accordingly, the structural changes were also driven by the environmental conditions. Floristically, north facing slopes revealed high biodiversity. North facing slopes were mainly dominated by humid loving species contrary to xeric type along the south facing slopes.

In this regard, an influence of slope-aspect is critical for the choice of species (site specific) for the plantation to be successful. Xeric type of species (*Pinus*, *Zizyphus* or *Desmodium*) should be selected for the lower, drier south facing slopes while mesic type of species (evergreen or deciduous broad-leaved) should be selected for the north facing, humid slopes respectively. Similarly, selective logging or traditional harvesting of timbers should be recommended mainly for the south facing slopes. Importantly, forest fire should be prevented along the south facing slopes owing to its dry biomass and dryness. Therefore, the findings of the study may help to manage the forest on a sustainable basis.

Photo 2. Distinct floristic composition along north and south facing slopes. North facing slopes were dominated by deciduous broad-leaved and pine conifers on the south facing slopes.

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Technical Comments on the Design and Designation of Biological Corridors in Bhutan: Global to National Perspectives

Phuntsho Thinley[1]

ABSTRACT

There are increasing numbers of scientific publications supporting the seemingly cliché in conservation biology that habitat loss and fragmentations are the driving forces of rapid biodiversity loss across the globe. In the wave of efforts to counter the effects of fragmentation and in search for effective ways to provide connectivity between wildlife metapopulations, biological corridors have been sought as one of the promising means to foster genetic exchange and counter inbreeding depression. Even an underdeveloped but habitat rich country like Bhutan is not spared from the impending threats of biodiversity loss in the wake of globalization, developmental activities and rapid population growth. The threats to and challenges of biodiversity conservation are mounting every year, which is why the country has dedicated about 10 percent of the country for biological corridors. I offer some technical comments on the current status of corridors in Bhutan by providing both global and national perspectives and drawing from the general concepts that have evolved from the scientific inquiries on corridor issues. As with the rest of the world, Bhutan has followed a similar pattern of using specific criteria and tools in selecting corridors. Interestingly, situations in Bhutan are unique needing some in-depth considerations due to mountainous terrain, wide elevation range and wide range of habitat types.

KEY WORDS: Biodiversity, connectivity, metapopulations, biological corridors, genetic exchange, inbreeding, mountainous terrain, wildlife

INTRODUCTION

Until recently, most animal species lived in well connected landscapes (Beier and Noss, 1998). Wild animals are now being compacted into

[1] Park Manager, Jigme Dorji National Park, Gasa, Bhutan. Also a PhD student at Cornell University, NY, USA.

isolated pockets, which are often small enough to be called viable entities (Rosenberg, 1994). These small populations of wild animals are vulnerable to further shrinkage and ultimate extinction due to increased likelihood of edge effects and genetic depression (Noss et al., 2006). The current world is witnessing an unprecedented rate of species extinction and biodiversity loss due to habitat loss and fragmentation caused by increasing development activities and expanding human settlements (Anderson and Jenkins, 2006). There are claims that many of the protected areas and biosphere reserves around the world are not big enough to sustain a viable population of large ranging animals (Bennett, 2003; Hilty et al., 2006) . Hence, there is a growing recognition and need for connectivity between these isolates to ensure the long term viability of animal population and integrity of ecosystems at large. Therefore, biological corridors are large-scale landscape linkages created or maintained for movement, migration, and dispersal of large-ranging wild animals. The linkages may be in the form of landscape mosaics, stepping stones (discrete patches of forest cover between two large habitats), and linear habitats connecting two large habitats (Bennett, 2003). However, the different forms of linkages have been implemented without much practical information to guide their design, location, and management (Lindenmayer, 1993; Bennett, 2003).

The paucity of empirical studies authenticating the efficacy of biological corridors as effective conduits of species (Simberloff et al., 1992; Lindenmayer, 1993) has provoked many scientific debates about the benefits of corridors (Simberlof and Cox, 1987). Yet, their acceptance as a conservation strategy has far superseded the pace of research efforts to prove their worth as the most effective ways of biodiversity conservation (Rosenberg, 1994; Bennett, 2003; Anderson and Jenkins, 2006). The Pan-European Ecological Networks and the Mesoamerican Biological Corridor are classic examples of corridors at large scale.

Bhutan also joined this bandwagon in 1998. Strongly recognizing the critical need for habitat connectivity between the protected areas, the government has designated approximately 10% of the country as biological corridors (Fig. 1). Policy makers thought that even though the country enjoys the wealth of 72.5 percent forest cover (DoF, 2002), developmental activities are increasing rapidly coupled with rapid population growth. Threats to biodiversity are mounting, and there are increasing evidences of habitat fragmentation caused by numerous road

constructions, expanding settlements, rapid urbanization, increased mining, repeated forest fires (Mackinnon, 1998; NCD, 2003), and increased construction of hydropower dams. In addition, most of the faunal species, including globally threatened and endangered species such as takin (*Budorcas taxicolor*), musk deer (*Moschus chrysogaster*), red panda (*Ailurus fulgens*), and snow leopard (*Uncia uncia*), occupy small habitat ranges in the country (Mackinnon, 1998). Hence, there is an impending risk that most of the wild animals will be confined into isolated pockets despite their low population density (Mackinnon, 1998).

Objectives

Most of the corridor concepts worldwide are conceived on relatively flat terrain and plain areas.
Hence, this paper is aimed at drawing attention of the corridor scientists and wildlife biologists to the issues related to efficacy of corridors in predominantly mountainous areas. The other objective of this paper is to provide technical comments on the design of corridors in Bhutan which could help the process of framing policy and management modalities of the corridors. Such a preemptive exercise is timely and relevant while Bhutan has the advantage of good forest cover connecting the protected areas. This could enable readjustments and realignment of corridors as deemed fit before these precious natural linkages are permanently lost to ensuing development activities.

Review of global perspectives on corridors

Different forms of habitat connectivity across the world
Most of the efforts worldwide in creating connectivity are in planning stage or launching of hundreds of corridor projects (Anderson and Jenkins, 2006). The linking habitat already exists in majority of the cases but is not designated or managed as a link (Bennett, 2003).

Throughout the world, the concept of connectivity and corridors have been conceived in the forms of biological corridors, ecological corridors, landscape linkages, land bridges, greenways (the USA and Australia), shelterbelts, ecoducts (Netherlands), habitat corridors, wildlife corridors, dispersal corridors, and movement corridors based on functionality at different spatial and temporal scales. The scale of operation varies greatly from underpasses and short habitat corridors to major landscape links

measuring many kilometers. In Africa, N. America, and Europe, human settlements and other developments block the traditional pathways and migratory routes of large terrestrial herbivores. So, artificial linkages such as tunnels and highway underpasses have been used for the effective passage of wild animals (Bennett, 2003).

Due to large arrays of synonyms and concepts for biological corridors, Anderson and Jenkins (2006) have broadly classified them into two types: *Linear corridors* linear connections between large habitat blocks extending over tens of kilometers) and *Landscape corridors* (multidirectional connections over entire landscapes encompassing thousands of square kilometers).

Criteria used for corridor design across the world

Most of the biological corridors in the world have been designed based on the habitat range, habitat status, and distribution patterns of keystone or umbrella species. Some example are the tigers (*Panthera tigris*) and greater one horned- rhinoceros (*Rhinoceros unicornis*) in the Terai Arc Landscape of Nepal and India; Florida panther (*Felis concolor coryi*) for Pinhook and Panther Glade corridors in Florida, USA; lion tamarins (*Leontopithecus rosalia*) in the Atlantic Forests of Brazil; and grizzly bears (*Ursus arctos horribilis*) and wolves (*Canis lupus*) in the Yellowstone to Yukon (Y2Y) corridor, USA and Canada (Anderson and Jenkins, 2006). But in Europe, the selection criteria for ecological networks range from target species to biodiversity at large (Table 1). In Northern Belize Biological Corridor project, the suitable habitat type map was superimposed with human settlement map and land tenure map to piece out suitable and pragmatic corridors (Meerman et al, 2000). Rouget et al (2006) while designing landscape corridors in the Subtropical Thicket Biome of South Africa, developed criteria to represent maximum biodiversity pattern and capture key environmental processes aligned along elevation and climatic gradients. They included (1) presence of subtropical thicket vegetation and its condition, (2) the occurrence of process components, (3) the degree of suitability of wildlife habitat, (4) the location of protected areas, and (5) future land-use pressures. The African Elephant (*Loxodonata Africana*) and black rhinoceros (*Diceros bicornis*) were the two mega-herbivores set aside as the focal mammal species for connectivity.

Table 1. List of criteria used for establishing ecological networks in some European countries (Source: Jongman and Kristiansen, 2001)

Country	Criteria used
Belgium	Biodiversity, sustainability, representativeness, and vulnerability
Estonia	Social and ecological features
Germany	Biotope types and selected species
Poland	Status, distribution, and sites of certain target species, geomorphological structures, hydrological conditions, and landscape structures
Portugal	Gap analysis results
Russia	Low rate of anthropogenic disturbance and a relatively high native biodiversity

National Perspectives on Biological Corridors

Origin of corridor concept in Bhutan

The concept of corridors is fairly new to Bhutan. In 1998, about 10 percent of Bhutan's total area was designated as biological corridors interlinking the 10 protected areas, largely based on the results of the nationwide tiger survey carried out by Nature Conservation Division (NCD) in 1998. In the same year, this network of protected areas was offered as "Gift to the Earth from the People of Bhutan" by Her Majesty, Ashi Dorji Wangmo Wangchuck.

Types of Corridors in Bhutan

Three types of permanently forested habitat corridors were proposed based on their level of protection:

i. Biodiversity Corridors: To facilitate the movement of long ranging mammals between protected areas for gene flow and continued survival of the population. The minimum width of such corridors was fixed at 2 kilometers and any activities deemed to constrict the corridors to less than 2 km were not be allowed.

ii. Critical Corridors: These are in other words termed as "bottle-necked corridors" where the constrictions are much below the minimum width of 2 km and are liable to severed in presence of slight human activities.

iii. Sites of Full Protection: Small sites where additional protection are needed such as catchments protection, road protection, stream bed protection or protection of sites of religious significance coinciding with the need to protect a critical biodiversity corridor (Mackinnon 1998).

Criteria used for designing corridors in Bhutan

Corridors were designated using GIS technology that used spatial layers of vegetation types derived from Landsat images, landuse maps, and GPS points of tiger evidences. Suitability scores were assigned against a particular area using various landscape features and components (Table 2). Guided by the land-use map, habitat features consisting of broadleaf forests, conifer forests, natural pastures and water bodies were favored whereas permanent snow and ice, bare rock, cleared land and landslips, agricultural lands of all classes, plantations, urban areas and roads were excluded. Corridors were considered highly suitable if they had good canopy and ground cover, little human disturbance, moderately steep terrain of low value for agriculture or pasture, signs of key wildlife species and have a width of more than 5 km. Areas on the corridors where the width is less than 1 km, were termed as bottlenecks.

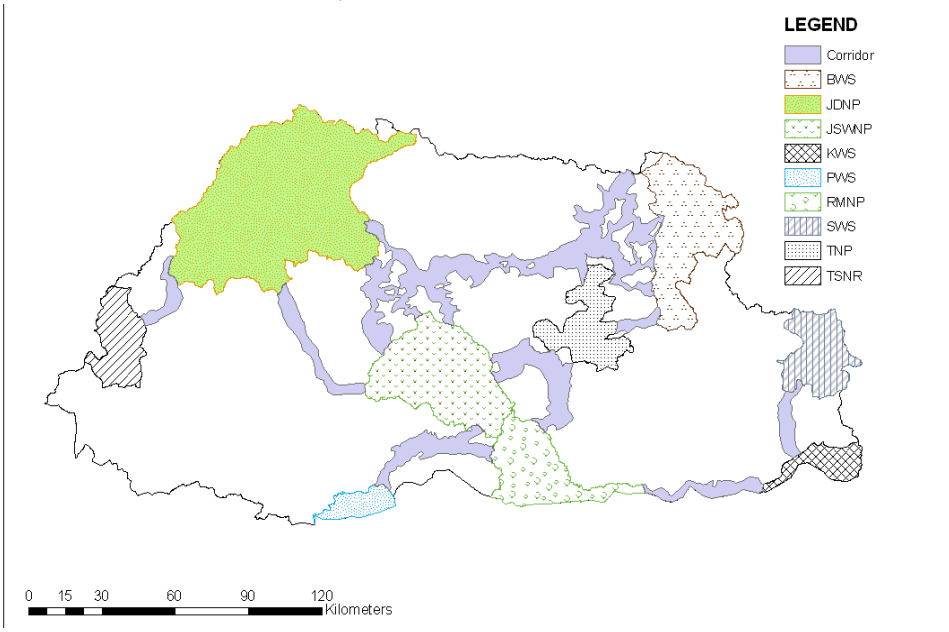

Fig. 1. A 1998 map of Bhutan showing biological corridors connecting protected areas (Source: NCD). Wangchuck Centennial Park, which was designated later in 2008, is missing.

Corridor projects in Bhutan

In 2003, the management of Thrumsingla National Park undertook a pilot project called LINKPA (Linking and Enhancing Portected Areas in the Temperate broadleaved forests Ecoregion of Bhutan) funded by WWF and UNDP-GEF that focused on studying socio economic conditions and implementing integrated conservation development programs (ICDPs) in two corridors: i) Thrumshingla National Park (TNP) – Jigme Singye Wangchuck National Park (JSWNP) and ii)TNP – Royal Manas National Park (RMNP) (TNP, 2003). The outcomes from this project was used as the basis for development of corridor management guidelines that culminated in addition of a chapter on biological corridors to the Forest and Nature Conservation Rules of 2006 (Johnsingh and Norbu, 2006). Moreover, the Government has bolstered the national view on biological corridors by incorporating them into the countrywide landscape approach to conservation called the Bhutan Biodiversity Conservation Complex (B2C2) (NCD, 2004).

In 2004, NCD undertook rapid biodiversity and socio-economic surveys in the corridor connecting Jigme Dorji National Park (JDNP) and Toorsa Strict Nature Reserve (TSNR), and developed a strategic plan to manage the corridor (NCD, 2008).

Table 2. Criteria used for designation of Bhutan's corridors (Source: Mackinnon, 1998; also cited by Dorji, 2000)

Component factors	**Scores**
Abundance of target wildlife or their prey	High=1, Medium=0, Low =-1
Slope of terrain	Very steep=0, *moderate=1, gentle=-1
Absence or rarity of forest fires	Never/rare=1, occasional=0, annual=-1
Condition of habitat canopy and undergrowth	Good=1, Medium=0, Poor=-1
Levels of human disturbance	Low=1, Medium =0, High = -1
Width of narrowest constriction	>3km=1, 1-3km=0,<1km=-1

**Moderate slope being the ideal between useable for wildlife but less attractive for human agriculture.*

The total sum scored for each corridor gave its overall suitability as a corridor with >2 rated as highly suitable, 1-2 rated as moderately suitable, 0 as lowly suitabile, and less than zero as unsuitable.

In literal terms, corridors were considered highly suitable if they had good canopy and ground cover, little human disturbance, moderately steep terrain of low value for agriculture or pasture, many signs of key wildlife species and of they had a width of more than 5 km. Areas on the corridors where the width is less than 1 km, were termed as bottlenecks (Mackinnon, 1998).

Current status of corridors in Bhutan

At present, most of the corridors exist only on paper without proper ground truthing and field verifications, mainly due to lack of trained manpower and resources. Not a single empirical study has been done to test the functionality of the corridors in terms of their usage by target wildlife species. A national program coordinator was appointed at Nature Conservation Division under the Department of Forests and Park Services to oversee the drafting of corridor management framework and policy. Practically, the corridors are right now managed without management framework, policy, and plans by Divisional Forest Officers who manage the Government Reserved Forests outside the protected areas.

Technical comments and recommendations for design of corridors in Bhutan

While most countries in the world are facing great dilemma on the creation and restoration of corridors due to extensive human settlements and developmental activities that have led to large scale habitat fragmentation and isolation, Bhutan is comparatively in a better position with huge contiguous tracts of forest cover due to which most of the habitats in the corridors are still intact.

Looking at the map of protected areas network with biological corridors connecting all protected areas, an outsider and a layperson would be tempted to assume that the areas outside the network are either barren or largely degraded and unfit for wildlife movement while in reality, in some areas, habitat conditions outside the corridors and protected areas are much better than those inside. Hence there is no need for major

restoration or creation of habitats in the corridors, nor there is a need to install expensive structures such as overpasses and underpasses. Since there are better habitats even outside the currently designated corridors, the focus of corridor management is to identify and preserve the best habitat linkages between the protected areas before they are permanently lost or degraded. Therefore, rigorous field studies and on site verifications are much needed to be done as early as possible to identify the best wildlife habitats that will facilitate unhindered movement of target animals between the protected areas. Bhutanese conservationists should realize that the best natural connectivity once lost is neither easy nor cost effective to reestablish. When there is plenty of room to make pre-emptive decisions about best corridor management, policy makers and corridor managers should make best avail of this opportune time.

Despite the great influences of socio-economic situation of the villages and the types of current landuses around the corridors on the effectiveness of corridors (Harrison, 1992), they have not been incorporated into the list of criteria for designation of corridors in Bhutan, except by the management of TNP for the corridors connecting TNP to RMNP and JSWNP. Therefore, design of corridors in Bhutan should incorporate the socio-economic situations of the villages lying inside and adjacent to corridors.

Another important aspect that Bhutanese corridor managers and designers should take note is the fact that most of the international concepts of corridors are based on studies conducted in relatively flat areas with no drastic changes in habitat and altitudes along the corridors (Bennett, 2003; Hilty et al., 2006). Bhutan being a predominantly mountainous country has mountain ranges comprising various habitat types, ranging from sub-tropical broad-leaved forests to alpine meadows and screes. Land gradually rises, hence huge elevation change, from the southern foothills to till the Greater Himalayas. Also, most mountain ranges run north to south. Corridor designers in Bhutan should, therefore, first determine if the corridors are passing along a mountain range (N-S corridor) or crossing several mountain ranges (E-W corridor). Habitat specialists (animals living in specific habitat type) will prefer the former type while habitat generalists will prefer the latter type. Then utility of the corridors for target animals such as habitat specialists and generalists, and long-ranging and short-ranging should as assessed accordingly. Lindenmayer (1993) stated that the corridors connecting gullies to ridges supported

more species (hence greater abundance of species) than those confined to a single topographic position such as a mid-slope. Yerena et. al (2003) stated that in mountains, habitat fragmentation can affect single ecosystem or habitat type as well as the continuity between different habitats or ecosystems along altitudinal gradients. Therefore, development planners should make sure that certain huge patch of forest cover is left between the groups of settlements on hills to facilitate safety passage of wild animals across a mountain or from a mountain base to top.

Also because of the mountainous terrain, actual length of corridors on the ground would be much longer than the map length. Hence, corridors cannot be too narrow and long (example between JDNP and JSWNP via Dochula) in order to avoid edge effects. If such circumstances are inevitable, plantations and restorations should be done in some portions of the corridor to provide foraging needs and cover for the focal species. Further, terrain ruggedness index should be accounted in designing corridors in order to determine the most favorable animal pathways with moderately steep and flat terrains where expenditure of energy is minimum.

In the critical corridors, the concept of habitat 'nodes' can be applied; where in some level of native habitat can be restored adjacent to the 'bottlenecks'. In addition, 'buffer zones' can be demarcated on both sides of the critical corridors for achieving maximum connectivity.
(Noss, 1987) Planners and environmentalists are busy drawing corridors into their decisions, sometimes with only a vague awareness of the biological issues underlying the corridor strategy.

Therefore, as asserted by (Rosenberg, 1994), if increased connectivity of otherwise isolated populations is desired for ensuring population persistence, corridor managers need to consider how organisms move across the landscape. Simply providing a linear patch of natural habitat may not suffice, but concurrent empirical studies should be carried out to determine the efficacy of corridor as an effective link between the protected areas. Field data need to be collected to establish some relationship between landscape features and animal occupancy or movement. In addition to the Least-Cost Model (Adriaensen et al., 2002) some of the latest corridor design models such as Circuit Theory Model

(McRae et al., 2008) based on real landscape data should be adopted to identify the most effective corridors.

Many features of landscape that currently fulfill the role of corridors, such as hedge rows, riparian habitats (see Tabacchi et al., 1998; Hilty and Merenlender, 2004) fence rows, shelterbelts and roadside vegetation (see Saunders and Hobbs, 1991) needs to be incorporated into the landscape approach to biodiversity conservation. The potentials of certain habitat patches as stepping stones for birds and other large ranging mammal species were not explored. Migratory corridors were never mentioned and included in the biological corridors. For instance, takins in JDNP migrate from Tsharijathang (summer habitat) to Tashithang (winter habitat). There are no alternative migratory paths at some points, and if these crucial paths are not protected, the population may not be able to migrate. All of these should be incorporated into the integrated concept of biological corridors and landscape approach to biodiversity conservation.

From the policy perspective, as resolved during the National Consultative Workshop on Biological Corridor Framework held at Khuruthang, Bhutan from 15-17 March 2010, the status of biological corridors should be elevated to that of protected areas to ensure proper regulation of activities inside the corridors. There should be separate policy and guidelines on regulating developmental activities, harvesting of natural resources, community forestry, ecotourism, sustainable livelihood enterprises, and forest management units within the corridors in order to maintain their inherent connective property. Multifunctional corridors that cater to ecotourism, sustainable agriculture, watershed conservation, and recreation should be emphasized and prioritized. Besides, Community Forests should be encouraged in the biological corridors because resources will be more sustainably used and forest cover will last longer if community participation in the management and ownership of resources are encouraged.

From the management perspective, corridors will be best managed if management responsibilities are handed over to the territorial Chief Forest Officers who manage the Government Reserve Forests outside the protected areas after Nature Conservation Division prepares comprehensive management plans for all corridors. However, currently, these officers and their staffs lack capacity to manage the corridors in

addition to absence of clear boundary demarcations on the ground. The process of ground truthing and preparing management plans should be expedited, as development activities are increasing through time. Expatriates should be hired to prepare management plans if local officials are inadequate.

From the perspective of climate change, the value of corridor is more emphasized in its potential to ameliorate the impacts of climate change (Noss, 1993; Harris et al., 1996; Williams et al., 2005) by providing escape paths for wild animals from areas affected by drought, flood, and increasing temperature. However, those groups of wild animals that are confined in a particular area, e.g. alpine areas, and specialized to a particular habitat type will be most affected by climate change (Peters and Darling, 1985). Since the corridors are designed for tiger movements, some of the north-south corridors should be increased in width, particularly the one connecting JSWNP and JDNP. Thinley (2008) while designing a map of optimal tiger habitats in the country has recommended that this corridor should be expanded more towards the east to encompass more of the optimal areas for tigers. He also recommended establishing one more corridor to connect Toorsa Strict Nature Reserve with Phibsoo Wildlife Sanctuary.

Since, biological corridors are not the sole efficient means of biodiversity conservation, the establishment of narrow, linear corridors should not be considered as an alternative to increasing the area of existing reserves if the long term goal is to conserve biodiversity (Rosenberg et al., 1997). As such, in conjunction with the designation of corridors, reserve sizes and corridor widths should be increased as much as desired, as the current political environment in Bhutan is ideal for conservation, and also there is plenty of room for expansion. In certain cases, alternatives such as translocation of the animals should also be considered. Further, anti-poaching of wild animals needs to be intensified in the protected areas and corridors, because corridors will have no value if populations of wide-ranging animals are greatly reduced below minimum viable levels or driven to extinction due to extensive poaching.

CONCLUSION & RECOMMENDATIONS

Due to vast contiguous tracts of forests in Bhutan, there is adequate natural habitat connectivity between its protected areas. Most potential

and crucial links should be identified through empirical studies at the soonest possible before they are permanently lost to development activities. The design of corridors should consider the latest developments in corridor science and some of the limitations and issues posed by predominantly mountainous terrain and unique socio-economic and cultural settings of the country. Separate policies should be developed for corridor management with special reference to regulation of development activities that might undermine the connective potentials of the corridors. Role of corridors in improving the resilience of wild animals toward climate change should be emphasized. Finally, in conjunction with designation of corridors, some of the protected areas should be expanded wherever possible to encompass more wildlife habitats.

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Understanding the pattern of spatial co-occurrence between tigers, leopards, and black bears in Bhutan through spatial point pattern analysis of their livestock depredation sites

[1]Phuntsho Thinley

ABSTRACT

A study of the pattern of co-occurrence among wild animal species using spatial analysis of their occurrence points is a new concept. Bhutan has many species of mammalian predators of which tigers (*Panthera tigris*), leopards (*Panthera pardus*), dholes (*Cuon alpinus*), and Himalayan black bears (*Ursus thibetanus*) have been reported to kill livestock probably because of decline in their natural prey population and lax herding practices. About 46 cases of livestock depredations by tigers, leopards, and black bears were reported during the year 2005 from Jigme Dorji National Park (JDNP), Jigme Singye Wangchuck National Park (JSWNP), and Bumdeling Wildlife Sanctuary (BWS). Past studies suggested increasing dependence of these predators on livestock in Bhutan which merits an examination of their spatial co-occurrence in their livestock depredation sites. I determined the spatial co-occurrence among tigers and leopards, and leopards and bears using the Global Positioning Systems (GPS) points of livestock depredation sites in Bhutan reported by field staffs. Ripley's K was used to test for spatial randomness of tiger, leopard, and Himalayan black bear kill sites while Cross-K was used to test for spatial co-occurrence of tigers and leopards in JDNP and leopards and Himalayan black bears in BWS. Tigers, leopards, and bears kill sites were not spatially random but clustered with most clustering occurring in the case of leopard kill sites. There was no evidence of spatial co-occurrence of leopards with tigers in JDNP and leopards with Himalayan black bears in BWS.

INTRODUCTION

Spatial co-occurrence between sympatric carnivores in the light of domestic prey selection has not been studied till date. Moreover, the study

[1] Park Manager, Jigme Dorji National Park, Gasa, Bhutan

of the pattern of co-occurrence among animal species using spatial analysis of their occurrence points is a new concept. Only a few related studies have been conducted so far. For instance, Krester et al. (2006) have studied the spatial relationship between human-wildlife interactions and density of housing development. They have used univariate K-function (also called Ripley's K) to test for spatial randomness and dependence by analyzing the distribution of all reported human-wildlife interactions and a subset of five reported individual species-human interactions: black bear (*Ursus americanus*), white-tailed deer (*Odocoileus virginianus*), raccoon (*Procyon lotor*), striped skunk (*Mephitis mephitis*), and woodchuck (*Marmota monax*). Bivariate K-function (also called cross-K) was used to study the spatial relationship between the human-wildlife interactions and different types of land uses. Also, Rhinehart (2002) has studied the spatial patterns of bomas, cattle, small ruminants, wild buffalo (*Syncerus caffer*), and elephants (*Loxodonta africana*) using Ripley's K, and the spatial relationship between them using Ripley's Cross-K in Amboseli Region of Kenya.

Bhutan, a tiny Himalayan kingdom, has many predators, such as tiger (*Panthera tigris*), common leopard (*Panthera pardus*), snow leopard (*Uncia uncia*), clouded leopard (*Neofelis nebulosa*), dhole (Cuoun alpines), Himalayan black bear (*Ursus thibetanus*), wolves, lynx (*Lynx lynx*), Asiatic golden cat (*Catopuma temminick*) and marbled cat (*Felis marmorata*) (Wangchuck et.al, 2003). But, more than 60% of Bhutanese are farmers who merely sustain on subsistence-based farming, which includes livestock rearing (NCD, 2003). Poor herding practices (Wang and Macdonald, 2006) and low natural prey density were suspected to have exacerbated predation by large predators on domestic livestock (Wang, 2008). Quite often predated livestock were cows, bulls, horses, goats, yaks, donkeys, and mules (Sangay and Vemes, 2008). Since the top carnivores increasingly depend on livestock (Wang 2008), there is a need to understand whether they hunt livestock at the same place or in different places. Such an information will provide conservationist and wildlife managers to delineate livestock depredation hotspots for these top livestock predators. Therefore, this study attempted to understand the spatial co-occurrence among tigers and leopards, and leopards and bears using the GPS points of livestock depredations sites in Bhutan. Specifically, it was intended to test: 1) whether the kill sites of tiger, leopard, and bear are spatially random, uniform or clustered; and 2) whether the kill sites of leopards are spatially dependent on tigers or

bears. Another intent of this study is to raise awareness among wildlife biologists that such an exploratory tool exists for determining spatial co-occurrence or separation among wild animals.

2. Methods

2.1. Data processing

Only 46 cases of livestock depredations by tigers, leopards, and black bears with usable GPS points were reported during the year 2005 from Jigme Dorji National Park (JDNP), Jigme Singye Wangchuck National Park (JSWNP), and Bumdeling Wildlife Sanctuary (BWS). Most of the GPS points submitted later were not usable because of excessive error and absence of proper information on Datum used. There were only 4 points from JSWNP; so, they could not used for analysis. Data transformation was done such that the northing and easting of each GPS location where livestock predation occurred were subtracted by their respective means, and were called northing2 and easting2 respectively. This was done to scale the eastings and northings in order to plot the points properly, because GPS points were recorded in Universal Transverse Mercator coordinate system, which produces huge numbers that are hard to plot (Table 1 and Table 2). The GPS points for livestock depredation in JSWNP were omitted because there were only three points; such a few points is not worthy of any interpretation. The plots of each predator species in each protected area is shown in figures 2-7.

Table 1: Livestock depredation points in Bumdeling Wildlife Sanctuary

Easting	Easting2	Northing	Northing2	Predator
2893428	1909	1127555	8109	Leopard
2893715	2196	1127268	7822	Leopard
2894002	2483	1123539	4093	Leopard
2885682	-5837	1124973	5527	Leopard
2885019	-6500	1097695	-21751	Leopard
2881875	-9644	1105705	-13741	Leopard
2892229	710	1127529	8083	Leopard
2895194	3675	1125525	6079	Leopard
2895889	4370	1123307	3861	Leopard
2894726	3207	1111497	-7949	Leopard
2892854	1335	1124400	4954	HBBear
2898305	6786	1124113	4667	HBBear

2892280	761	1122105	2659	HBBear
2881355	-10164	1110911	-8535	HBBear
2896231	4712	1115567	-3879	HBBear

Table 2: Livestock depredation points in Jigme Dorji National Park

Easting	**Easting2**	**Northing**	**Northing2**	**Predator**
2714127	-1695	1109195	1581	Leopard
2711545	-4277	1100588	-7026	Leopard
2712692	-3130	1117228	9614	Leopard
2718143	2321	1112351	4737	Leopard
2713266	-2556	1108621	1007	Leopard
2717283	1461	1106613	-1001	Leopard
2714414	-1408	1106613	-1001	Leopard
2712979	-2843	1107187	-427	Leopard
2713266	-2556	1109195	1581	Leopard
2713553	-2269	1109769	2155	Leopard
2717220	1398	1104792	-2822	Leopard
2713792	-2030	1102682	-4932	Leopard
2722505	6683	1090106	-17508	Leopard
2716329	507	1100174	-7440	Leopard
2713885	-1937	1104677	-2937	Leopard
2711923	-3899	1109791	2177	Leopard
2720479	4657	1108955	1341	Leopard
2716974	1152	1110941	3327	Leopard
2711905	-3917	1109381	1767	Leopard
2729054	13232	1111413	3799	Leopard
2714635	-1187	1112131	4517	Leopard
2710633	-5189	1111310	3696	Leopard
2722759	6937	1100836	-6778	Leopard
2713266	-2556	1117228	9614	Tiger
2714414	-1408	1110916	3302	Tiger
2718259	2437	1103133	-4481	Tiger
2717898	2076	1109751	2137	Tiger

2.2. Data Analysis

Spatial randomness or dependence within the kill sites of each predator was tested using Ripley's K. For testing the co-occurrence of leopards and tigers, and leopards and bears, Ripley's Cross-K was used.

2.2.1. Ripley's K or Univariate K function

Ripley (1976) defined a univariate K-function, commonly known as Ripley's K, to assess complete spatial randomness or spatial dependence of an event. The event in this study refers to the spatial distribution of leopards, tigers, and bears based on their livestock kill sites. A moving average is used wherein average of all observed points located within a certain arbitrary distance (h) from one observed point as center is calculated. This process is continued until all observed points have been used as the center point. Cressie (1993) provided the equation for Ripley's K as:

$$\hat{K}(h) = \hat{\lambda}^{-1} \sum_{\substack{i=1 \\ i \neq j}}^{N} \sum_{j=1}^{N} w(s_i, s_j)^{-1} I(\| s_i - s_j \| \leq h) / N, h > 0$$

where $\hat{\lambda}$ which is equal to N/A (such that N is the total number of events and A is the total study area) represents the intensity of the events. The indicator function $I(\cdot)$ identifies a point *i* within the data, noted as s_i ,which represents the location of the point *i*. In this study, s_i refers to the location of a tiger, leopard or bear. All other points *j* of tiger, leopard or bear occurring within the distance h from s_i are noted as s_j . $w(s_i, s_j)$ is an edge-correction factor which is equal to the circle centered at s_i inside the study area. The user determines the distance h based on the nature of the study and the data used. $\pi * (\hat{K}(h))^2$ that represents complete spatial randomness was used as the reference line to which $\hat{K}(h)$ line was compared. If $\hat{K}(h)$ line falls above the reference line, the data points indicate spatial dependence or spatial clustering. On the other hand, if $\hat{K}(h)$ line falls below the reference line, the data points indicate repelling of points from one another. Complete spatial randomness of data points of tigers, leopards, and bears was used as the null hypothesis in the study. S-Plus software program was used for the analysis of Ripley's K.

2.2.1. Cross- K or Bivariate K function

The cross-K is a modification of Ripley's K to enable characterization of spatial relationship between two different types of points within an area. The spatial relationship is characterized by repulsion or attract of two different sets of points. In an ecological sense, any attraction could be translated as co-occurrence and repulsion as avoidance of one species by another. In this study, cross-K was used to determine co-occurrence or avoidance of tigers and leopards in JDNP, and of leopards and bears in BWS.

Cressie (1993) provided the equation for Ripley's Cross-K as:

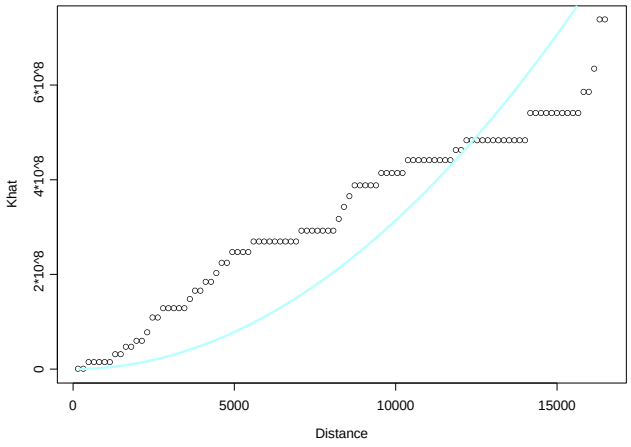
$$\hat{K}^{(A,B)}(h) = (\hat{\lambda}_A \hat{\lambda}_B)^{-1} \sum_{i=1}^{N_A} \sum_{\substack{j=1 \\ i \neq j}}^{N_B} w(s_i^A, s_j^B)^{-1} I(\| s_i^A - s_j^B \| \leq h) / N, h > 0$$

where the function identifies number of points of event B located within certain distance h from a point of event A. All other parameters were treated the same as in Ripley's K-function. Note that the cross-K function is only concerned about the presence of an animal species at a point, not the number of animals at that point (Rhinehart, 2002).

In order to compare the cross-K function, two envelopes, one comprising of maximum and minimum and the other comprising of 95% confidence intervals, were computed using Monte Carlo simulation where one thousand simulations were done for the same number of simulated points as in the original data set. If the plot of estimated cross-K function lies above the envelopes, the two different data points (e.g. leopards and tigers) are said to be attracted to one another, which means they are spatially correlated and thus co-occur with one another. On the other hand, the reverse situation would indicate that the data points repel from one another which means avoidance of tigers by leopards or vice-versa. R program was used for the analysis of Cross-K.

RESULTS AND DISCUSSIONS

3.1. Ripley's K



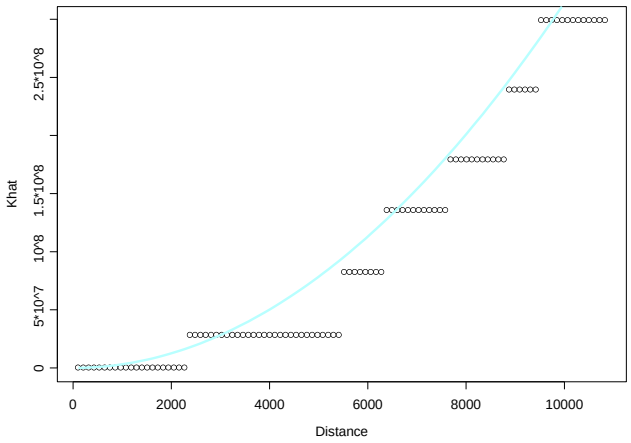
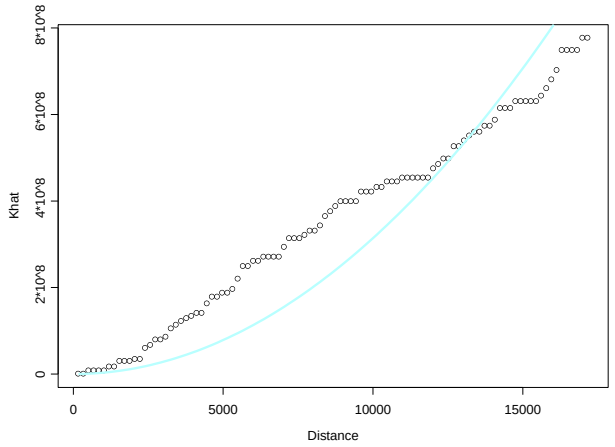


Fig. 1: Ripley's K for leopards in BWS **Fig. 2**: Ripley's K for Himalayan black bears in BWS

As indicated by Fig. 1, leopard kill sites in Bumdeling Wildlife Sanctuary (BWS) are clustered and thus spatially dependent. The plot for Himalayan black bear kill sites in BWS (Fig. 2) cannot be interpreted because of only 5 points. However, when combined, leopards and black bear kill sites were clustered in BWS (Fig. 3). This indicates within 1400 meters radius, chances of seeing leopards and black bears are high in the livestock depredation sites in BWS. If this is true, villagers should be careful while investigating leopard kills because they might encounter a bear. It is also likely that bears are following leopards to steal their kills.



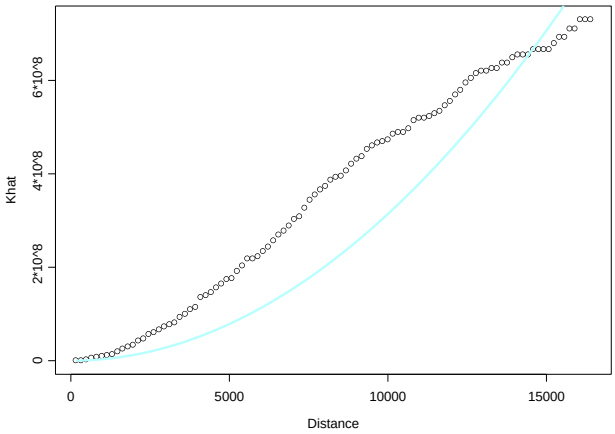


Fig. 3: Ripley's K for leopards and bears combined in BWS **Fig. 4**: Ripley's K for leopards in JDNP

As in BWS, leopards in JDNP are also found in clusters (Fig. 4) while pattern could not be deduced for tigers due to availability of only four data points (Fig. 5). As with leopards and bears combined in BWS, leopards and tigers combined are clustered in JDNP (Fig. 6). This indicates tigers and leopards predate on livestock nearby each other, but again not necessarily at the same time.

A common feature with leopard kill sites in both BWS and JDNP is that they are clustered. This indicates that leopards are found closer to one another while hunting for livestock, or a few leopards are mostly predating on livestock in JDNP and BWS. This could also mean that leopards concentrate predating on livestock in a particular area, probably

because there are more cattle or that cattle herders are not found in those areas.

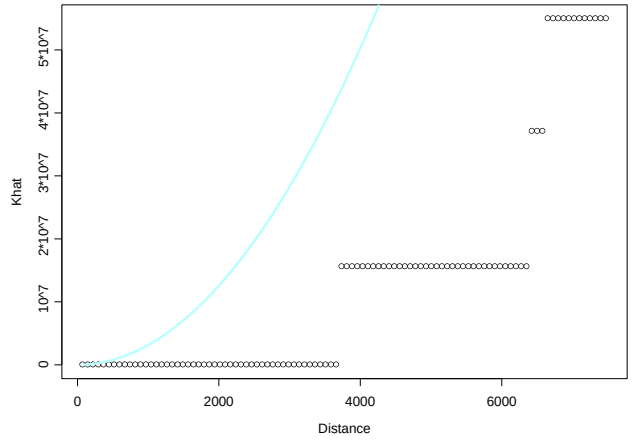


Fig. 5: Ripley's K for tigers in JDNP and leopards combined in JDNP

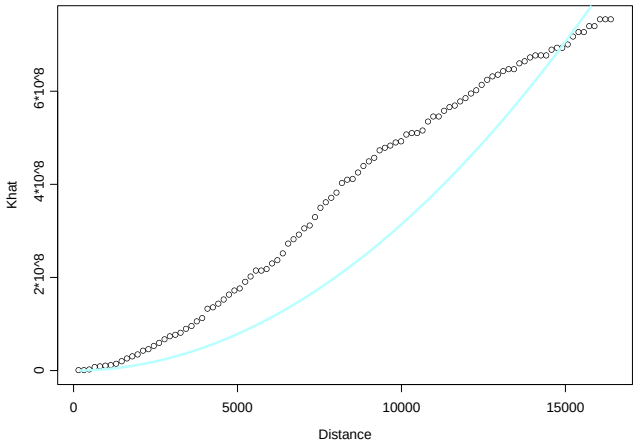


Fig. 6: Ripley's K for tigers

3.2. Cross-K

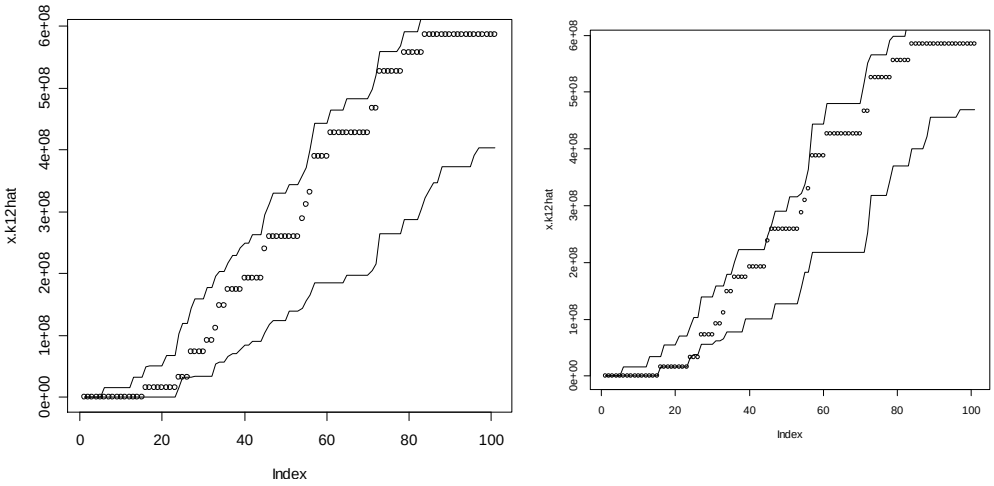


Fig. 7: Cross-K for leopards and Himalayan black bears in BWS with 95% confidence interval envelope (left) and minimum and maximum envelope (right)

The cross-K results for test of attraction or spatial dependence between leopards and black bears in BWS using both the 95% confidence interval and minimum and maximum envelopes (Fig. 7) indicate that these two animals are distributed randomly in space, as indicated by the cross K-plot lying completely inside the envelopes. They neither attract nor repel one another. In other words, leopards and black bears neither co-occur nor avoid each other in BWS, implying their occurrence is completely random.

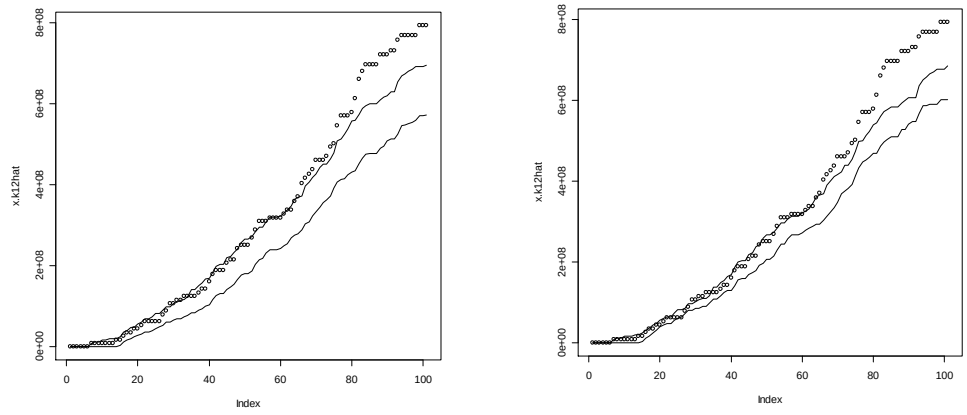


Fig. 8: Cross-K for leopards and tigers in JDNP with 95% confidence interval envelope (left) and minimum and maximum envelope (right)

The cross-K results for leopards and tigers in JDNP (Fig. 8) suggest similar pattern as with leopards and bears in BWS except that after 6000 m (or 6 km), the cross-K plot lies outside of the envelopes. So, at distances less than 6 km, leopards and tigers neither co-occur nor avoid each other. In other words, tigers and leopards are not found closer than 6 km in their pursuit of domestic prey. This is far removed from the pattern observed by Seidensticker (1976) in Nepal's Royal Chitwan National Park where tigers and leopards were found to be separated by minimum of 125 m. Obviously, the latter is an observation in a natural setting where both the cats co-existed due to large biomass of natural prey, large proportions of prey masses in smaller size classes, and dense vegetation structure.

Although, there were only 46 livestock depredation points that were usable and from which deductions were made, some of the results were highly significant, while some were discarded as not construable, explicitly stated in the above discussions. Therefore, the results and interpretations are valid.

CONCLUSION

Although its powerful utility is little known by wildlife researchers, spatial point pattern analysis can be a powerful exploratory tool in wildlife conservation. Applying this tool to GPS points of livestock depredation sites of tigers, leopards, and black bears in Bhutan, it was found that these predators are found in clusters which means they have their preferred livestock depredation sites that would probably indicate unattended release of livestock in the forests in particular spots. Livestock officers and wildlife conservationists should conduct a joint study about livestock herd management to reduce the cases of losses to wild predators.

Based on livestock depredation sites, leopards did not co-occur with bears at all distances in BWS; similarly, leopards did not co-occur with tigers at distances below 6 km in JDNP. Wildlife biologists may conduct further researches to confirm these findings to device proper precautionary notes for livestock herders.

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Determination of Shikimic Acid content in *Illicium griffithii* from Bhutan

Sharin Bin Ruslay[1], Masahiro Hatsu[1], and Peter Cheong Chiew Hing[1],
Tashi Y Dorji[2], and Singay Dorji[2.]

ABSTRACT

This study analysed the shikimic acid content in star anise (*Illicium griffithii Hook. F. & Thomson*), from *Bhutan as an additional potential source of shikimic acid. Star anise samples were collected from Menchuna in Thimphu, Yabrang in Trashigang and Aja in Mongar, Bhutan. Shikimic acid was extracted from the fruits after removal of seeds and analysed by High Performance Liquid Chromatography (HPLC). The results were compared to Chinese star anise (Illicium vercum Hook.F*.) *The analysis of star anise (Illicium griffithii) samples from Bhutan revealed a high content of shikimic acid, around 15-20 % in three samples from Yabrang, Trashigang. The content volume of shikimic acid in these samples was higher than that of the Chinese star anise sample analysed in this study as well as samples from other areas in Bhutan. Further comparison of the shikimic acid content analysis among the samples revealed that shikimic acid content was more in samples collected from standing tree than from the ground.*

The conclusion based on the results of this analysis indicates that star anise from Yabrang, Trashigang has high potential for industrial application and could also be explored as an additional source of shikimic acid especially in view of the increasing demand for anti-viral drugs against avian flu.

KEY WORDS: Star anise (*Illicium griffithii* Hook. F. & Thomson), Chinese star anise (*Illicium vercum* Hook.F.), shikimic acid content, High Performance Liquid Chromatography

[1] Nimura Genetic Solutions (M) Sdn. Bhd. Petaling Jaya, Selangor, Malaysia.
[2]National Biodiversity Centre, Serbithang, Thimphu, Bhutan

INTRODUCTION

Illicium griffithii Hook. F. & Thomson, commonly known as star anise is found in abundance in natural forest in six districts of Bhutan namely Chukha, Mongar, Samdrup Jongkhar, Trashigang, Trashiyangtse and Thimphu. It belongs to the family Illiciaceae and grows in sub-tropical and wet temperate broad- leaved forest. It is a glabrous and broadleaf evergreen medium size tree and usually found within the average elevation range of 1,200 and 3,000 metres above sea level. Trees are known to bear fruits approximately at the age of six years. The tree starts flowering from January to April. Fruiting begins from the end of April and starts maturing through September. The shape of the fruit is like a star with a radiating boat- shaped seedpod. Generally the fruit has 11 to 13 boat- shaped seedpods with incurved short beak. On average, in a good season, a tree is known to yield about six kilograms of fruits (Mukhia, 2006).

Traditionally its fruits are used as spice in cooking, preparation of local liquor to increase potency, as tea leaves and for fragrance in butter-tea and as incense. It is also used as a medicine for the treatment of cough, toothache and sinusitis. However, as per existing traditional knowledge, the consumption of seeds is known to be toxic causing serious vomiting which could be fatal at times. In addition to the above local uses, it is also recognized as a non-wood forest product whereby communities earn income through collection and sale. Currently there are only regional markets where the traders sell the collected fruits. The trade for this fruits had been introduced as early as the 1970s (Mukhia, 2006).

There is a growing demand for star anise as a source of shikimic acid for the manufacture of anti-viral drugs widely used in the treatment and prophylaxis of avian flu. Shikimic acid (Fig.1) is the starting compound utilized for the manufacture of the drug oseltamivir, which is expected to be used as a first line of defense in the event of an influenza pandemic (Bradley, 2005). Currently the Chinese star anise from China, *Illicium vercum* Hook.F., which is commonly used as a source of shikimic acid, mainly grows in four mountain provinces of Guanxi, Sichuan, Yunnan and Guizhou in China (Avula *et al*., 2009). It was originally used in traditional medicine of eastern Asia, where it is also cultivated (Lederer *et al*, 2006).

A shortage of star anise is one of the key reasons why there is a worldwide shortage of the anti-viral drug used against avian flu as of 2005 (Avula *et al*., 2009).

This study explores the possibility of using *Illicium griffithii* as an additional potential source of shikimic acid for the global fight against avian flu. The results are compared to Chinese star anise (*Illicium vercum* Hook. F.)

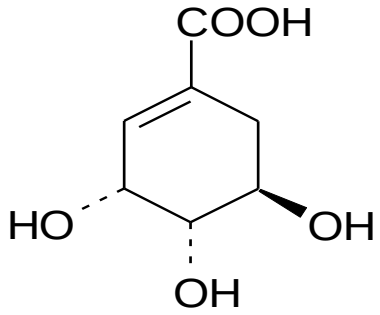


Fig. 1 Structure of Shikimic acid.

MATERIALS AND METHODS

Star anise (*Illicium griffithii*) samples.

Fruits of star anise (*Illicium griffithii*) were obtained from different areas in Bhutan. The samples were kept in a dry cold room prior to the analysis. Star anise samples and code:

1) **1A**: sample from Menchuna, Thimpu, from a standing tree in 2009.
2) **1B**: sample from Menchuna, Thimpu, from the ground in 2009.
3) **2A**: sample from Yabrang, Trashigang, (collection year unknown).
4) **2B**: sample from Yabrang, Trashigang, from the ground in 2004.
5) **2C**: sample from Yabrang, Trashigang, from the ground in 2009.
6) **3:** sample from Aja, Mongar, from the ground in 2009.
7) **4**: Chinese star anise (control: purchased from Chinese Medicine Shop in Malaysia)

Extraction method of shikimic acid from fruits

Seeds were removed from the pods of star anise. Then, the samples were pulverized using a blender. The rough powder obtained was sifted to get a

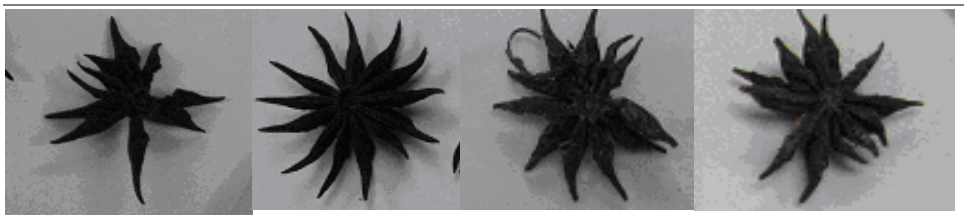
fine powder sample, particle size of 300 micron of the fruit of star anise. 1.5 grams of each fine powdered sample was dried in the oven at 120°C for 5 hours. One gram of each dried powdered sample was mixed with 20 ml of water in a 50-ml tube. The mixture was autoclaved at 121°C for 20 minutes and centrifuged at 8,000 rpm. The supernatant was filtered by 0.45 µm membranes. The extract was refrigerated at 4°C until analysis using HPLC. Then 20 µl of supernatant was transferred and diluted with 180 µl of water (10X dilution).

Analysis of shikimic acid by HPLC

The concentration of shikimic acid in the extracts of star anise samples was determined using an Agilent series 1100 HPLC chromatograph equipped with DAD UV detector using a detection wavelength of 230 nm. Separation was achieved on Agilent Exclipse XDB-C18 column (250 mm X 4.6 mm; 5 µm particle size). A flow rate of 1.0 ml/min was maintained at 30 °C. The injection volume was 10 µl. The mobile phase consisted of 0.2 % Trifluoroacetic acid (Solvent A) and MeOH (Solvent B). As for solvent system of HPLC, it is A: B = 95: 5 hold for 5 min, and it is carried out by linear gradient (from A: B = 95: 5 to A: B = 30: 70) for 25 minutes after that. The total run time was 30 min, with shikimic acid retention time at ca. 3.1 min. Good linearity was observed for the peak intensity within the specified shikimic acid concentration range. The correlation coefficient was 0.999. The LOD and LOQ were at 8 µg and 16 µg/ml respectively.

Compounds and Reagents

Shikimic acid was purchased from Wako Pure Chemical (Japan). Methanol and Trifluoroacetic acid used were of analytic or HPLC grade, purchased from Fisher Scientific (UK).



Sample 1A **Sample 1B** **Sample 2A** **Sample 2B**

Sample 2C **Sample 3** **Sample 4**

Fig. 2 Samples of *Illicium griffithii(1A,1B,2A,2B,2C,3) and Illicium vercum* Hook. F. (4).

RESULTS AND DISCUSSION

Results

Shikimic acid standard was detected at 3.10 min (Fig. 3) in a total of 30 minute run time. The typical analysis result of Bhutanese and Chinese star anise extract obtained with hot water extraction comparing to that of shikimic acid standard is also as depicted in Fig. 3. All extracts showed the presence of shikimic acid as a single major peak. The UV absorption of the major peak is of exact match to the UV absorption of shikimic acid standard for all the star anise tested (Fig. 4).

Based on the major peak area from the HPLC analysis, the content of the shikimic acid was calculated (Table 1).

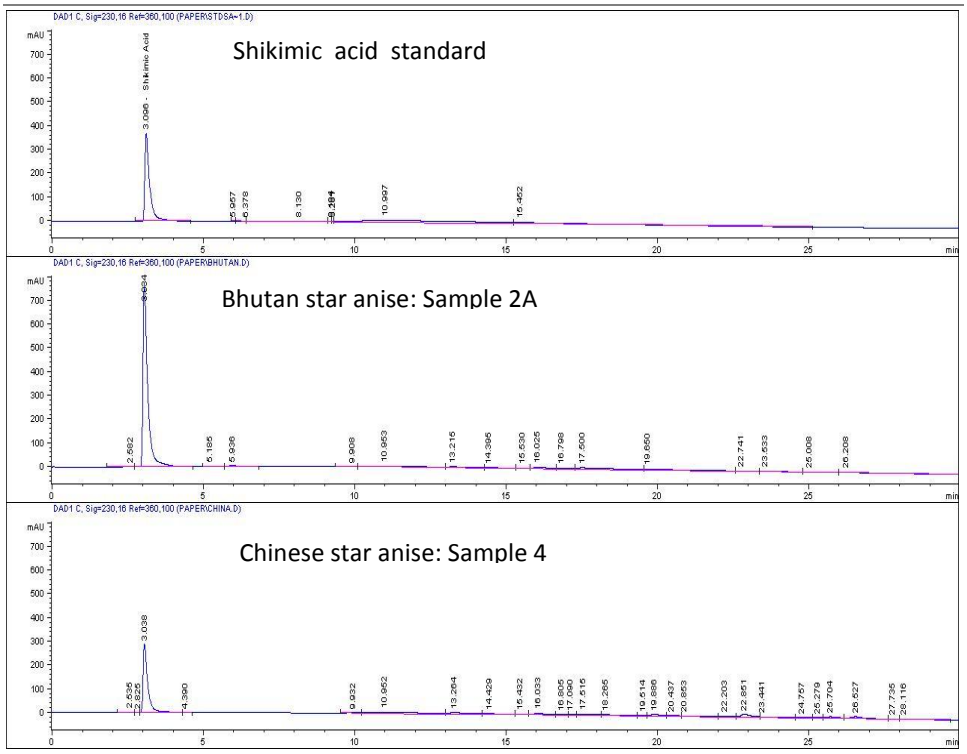


Fig. 3 HPLC chromatogram of shikimic acid standard, Bhutan star anise extract and Chinese star anise extract (UV at 230 nm).

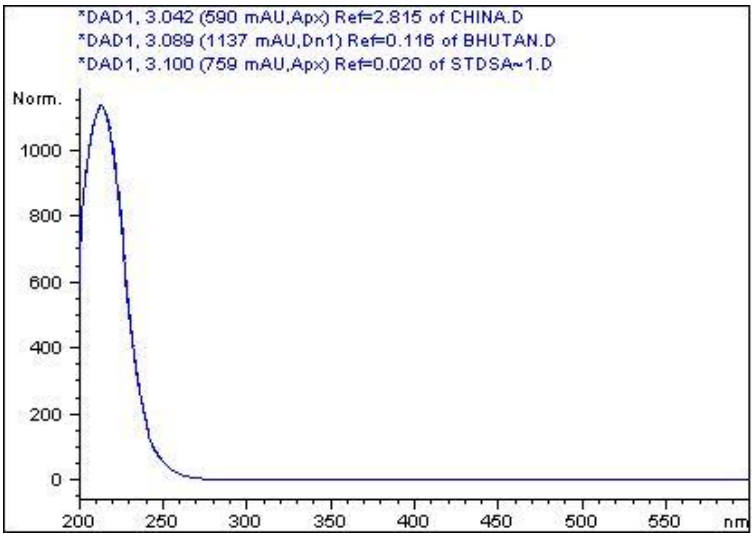


Fig. 4 UV absorption of major peak of shikimic acid standard, extracts of star anise from Bhutan and China.

Table 1 Shikimic acid content in various samples of star anise

Star anise	(% of Shikimic acid)	
	Injection 1	**Injection 2**
Sample 1A	8.10	8.03
Sample 1B	2.22	2.05
Sample 2A	20.26	19.66
Sample 2B	17.44	17.10
Sample 2C	16.06	15.06
Sample 3	10.47	10.47
Sample 4	7.83	7.42

DISCUSSION

Shikimic acid can be rapidly extracted from the pulverized seedpods particle size 355-600 □ m using hot water at temperature up to 150ºC without decomposition of the shikimic acid (Ohira *et al*., 2009). The extraction method and HPLC method used enable the analysis of shikimic acid without much interference from other compounds. The UV absorption of shikimic acid allows its detection at 230nm. Single major peaks detected at retention time ca. 3.1 min in each water extract of the star anise corresponds to similar retention time and UV absorption of standard shikimic acid.

The analysis of star anise (*Illicium griffithii*) samples from Bhutan revealed a high content of shikimic acid, around 15-20 % in samples 2A, 2B and 2C of Yabrang, Trashigang (Table 1). The content of shikimic acid in these samples is much more than that of Chinese star anise (sample 4), purchased from a Chinese medicine shop in Malaysia and that of star anise samples from other areas in Bhutan (sample 1A, 1B and 3). However further comparison of the shikimic acid content analysis among the samples revealed that shikimic acid content is more in samples collected from standing tree than from the ground. Sample 1A from a tree had shikimic acid content of 8.07 % as opposed to 2.14 % in sample 1B collected from the ground.

There is existing local knowledge on the toxic effects of seeds of star anise. There are also numerous scientific reports which describe clinical

toxicity, particularly adverse neurological effects. Sesquiterpene lactones have been isolated from a number of species of *Illicium*, and some of these compounds have been associated with neurotoxicity (Howes *et al*, 2009). Therefore, an important area of research identified is the analysis of toxicity of star anise.

The different levels of shikimic acid in the star anise samples from different regions in Bhutan also emphasizes the need to carry out systematic research on the effect of factors such as soil type, altitude, age of tree, time of collection and method of collection.

CONCLUSION

Six samples of Star anise (*Illicium griffithii*) from three different regions in Bhutan and one sample of Chinese star anise were tested for the analysis of shikimic acid. The content of shikimic acid in star anise from Bhutan was not confirmed before. Findings from this study have clearly confirmed the presence and level of shikimic acid in star anise from Bhutan. Star anise from Yabrang, Trashigang has a high shikimic acid content (around 15-20%). Based on the findings of this analysis, star anise from Yabrang, Trashigang could be studied further to explore its potential for industrial application and as an additional source of shikimic acid for manufacture of anti-viral drugs especially against avian flu.

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Physico-Chemical Characteristics of Surface Water in and around the Agriculture feild of Samtse District

Nandu Giri[1], O. P. Singh[2] and G. K. Chhopel[3]

ABSTRACT

Detailed studies on physico-chemical parameters of surface water in and around the agriculture field of Samtse district were carried out from June 2008 till May 2009 in all the three seasons namely, pre-monsoon, monsoon and post monsoon. Water samples (24) upstream and downstream of different agriculture areas were collected and analysed for temperature, pH, conductivity, total dissolved solids, turbidity, dissolved oxygen, total hardness, alkalinity, calcium, magnisium, nitrate, phosphate, chloride, fluoride, sulphate, iron, and biological oxygen demand. The results obtained were compared with the drinking water standards prescribed by Bureau of Indian Standards (BIS 10500:1991) and World Health Organization (WHO) as people living in this area directly use surface water for all domestic purposes. The study concludes that the surface water is suitable for domestic purposes. However, during monsoon season it is fit for drinking only after boiling. The organic farming carried out in the area has no major impact on water quality.

KEYWORDS: Physico–chemical parameter, Agriculture, Drinking water, WHO standards, Bureau of Indian Standards, Water quality

INTRODUCTION

Water quality is a vital issue because 1.1 billion of the world's 6 billion people do not have access to safe drinking water (World Health Organization, 2003). The freshwater resources are extensively used for various purposes and hence are increasingly subjected to environmental stress. There is a concern that in near future freshwater resources will further deteriorate both in quality and quantity in many parts of the world.

[1] Samtse College of Education, Royal University of Bhutan
[2]Department of Environmental Studies, North-Eastern Hill University, Shillong – 793022
[3]National Environment Commission, Thimphu Bhutan

Hanazato (1999) stated that global environmental problems such as climate change due to global warming, acid deposition and contamination with toxic chemicals are increasingly affecting the water ecosystem. The deterioration in the quality of freshwater resources is a serious challenge to sustainable development, health and sanitation, poverty reduction and biodiversity conservation.

The agriculture sector is by far the highest user of freshwater. About 67% of world freshwater is consumed for agricultural food production (UNESCO, 2000). It has been reported that agricultural activities affect water quality of nearby streams and rivers (Gaballah *et al.*, 2005). With the increase in population, the demand for food is increasing day by day. Tilman (1999) emphasized that intensive agriculture to double food production would have environmental impact on freshwater due to excessive release of nutrients into the water causing eutrophication.

Therefore, there is a need to create greater awareness and action plans to improve the quality and quantity of freshwater resources. Hence, for effective monitoring of water quality, regular analysis of physical, chemical and biological parameters is necessary.

The permissible limits for drinking water as laid down by the Bureau of Indian Standards (BIS 10500:1991) and World Health Organization (WHO) are shown in table 1.

Table 1. Drinking water quality standards as recommended by WHO and BIS.

Parameter	**WHO standards[a]**	**BIS (10500:1991) standards[b]**
pH	-	6.5 – 8.5
Dissolved oxygen (mg/L)	-	5
TDS (mg/L)	500	500
Chloride (mg/L)	-	250
Sulphate (mg/L)	-	200
Nitrate (mg/L)	50	45
Fluoride (mg/L)	1.5	1.5
Total Hardness as $CaCO_3$ (mg/L)	-	300
Calcium (mg/L)	100	75
Magnesium (mg/L)	150	-
Turbidity N.T.U	-	5
Iron (mg/L)	-	0.3

[a] *Maximum permissible concentrations*
[b] *Highest desirable limit*

The objective of the present study is an attempt for the first time to assess the physico–chemical characteristics of surface water in and around agriculture field in Samtse and compare it with the drinking water quality standards.

The study is carried out in Samtse district which is located in south west Bhutan (fig 1). The total area of Samtse is 1,582 Km^2 and its population is 60,100 (Population and housing census of Bhutan, 2005). The total cultivatable land in Samtse district is 17,917 hectares, out of which wetland has 3,474 hectares, dry land 12,066 hectares and orchard 2,377 hectares (Statistical year book of Bhutan, 2009) . The study area is situated between latitudes 26˚56“22’ to 26˚54“10’N and longitudes 89˚05“02’ to 89˚04“11’E. The main occupation of the people living in this area is agriculture and rearing of animals (cows, goats and pigs). The main food crops grown are maize and paddy. The farmers use only livestock manure in the agriculture field.

Fig 1. Location map of study area

The agriculture field within the study area is irrigated by the perennial streams of Budhuney and Dipujora. Irrigation channels are constructed from these streams to the paddy field. These streams originate from pristine forest area located above Tashim. It passes through agriculture field covering a distance of about 9.5 Km before draining into the State of West Bengal in India.

The total annual rainfall recorder is 4343.9 mm, out of which the total monthly rainfall ranged from 12.5 mm to 320.3 mm during pre- monsoon,

469.6 mm to 1304 mm during monsoon and 2 mm to 143.6 mm. during post monsoon.

MATERIALS AND METHODS

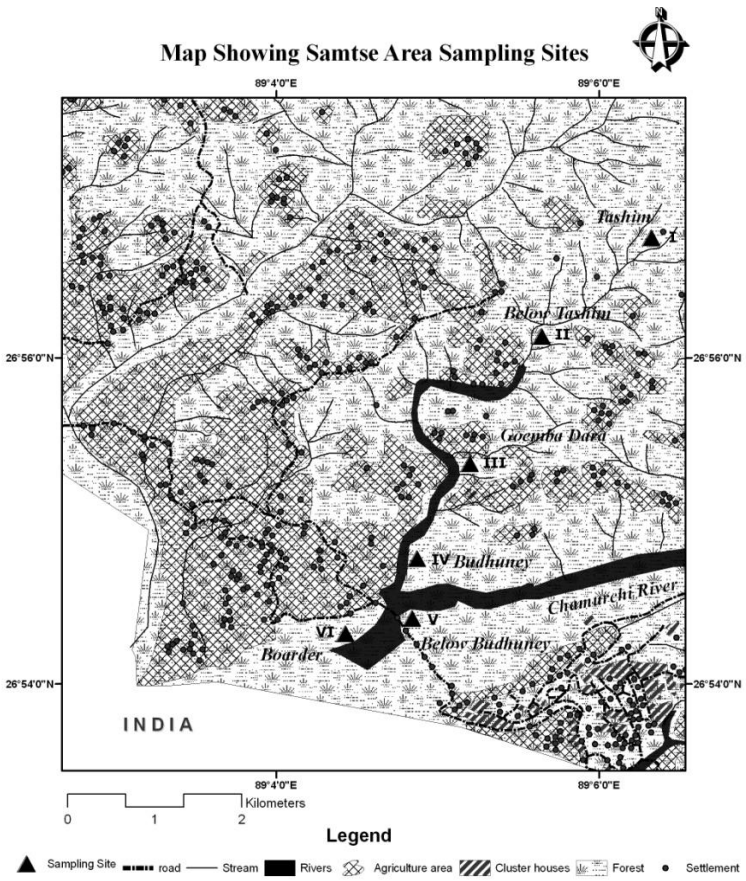
The water samples were collected in one liter sterilized polythene container using grab sampling method as outlined in American Public Health Association (APHA) Standard Methods for the examination of water and wastewater (2005). The water samples were collected from one foot below the surface of the water and immediately sealed with a stopper. Three replicates were taken for each parameter. In order to avoid bacterial growth in water, the samples were kept in an ice box and maintained a temperature of below 4˚C while transferring it to the laboratory.

The water samples were collected from six sampling sites from Budhuney stream and Dipujora streams as shown in table 2.

Table 2. Salient Features of sampling stations in and around agriculture field

Sl.No.	Study Area	Altitude (meters)	Longitude	Latitude
1.	Tashim (I)	640	89˚05“49’E	26˚56“22’N
2.	Below Tashim (II)	440	89˚05“15’E	26˚55“50’N
3.	Goemba Dara (III)	330	89˚04“40’E	26˚54“56’N
4.	Budhuney (IV)	315	89˚04“54’E	26˚55“17’N
5.	Below Budhuney (V)	280	89˚04“16’E	26˚54“16’N
6	Near Choiley Khop (VI)	280	89˚04“11’E	26˚54“10’N

Out of the six sampling sites, two sampling sites namely I and II are located upstream which is unaffected by agricultural practices, sampling sites III and IV are within the agriculture field and sampling sites V and VI are downstream of agriculture field. The map showing the sampling sites is given below.



The air and water temperature was recorded with the help of a Centigrade (0-110˚C) mercury thermometer, pH by using deluxe pH meter (model: EI products 101), electrical conductivity with Systronics conductivity meter (model: Systronics 304), turbidity with digital turbidity meter (model: EI Products 331), dissolved oxygen by Winkler's modified iodometric method at the sampling sites itself, alkalinity by titration method, total hardness, calcium and magnesium by EDTA titration method, iron by atomic absorption spectrometer (model: Perkin Elmer 3110), nitrate by phenol disulphonic acid (PDA) method using Systronics spectrophotometer (model: Systronics 169), phosphate by using stannous chloride method, Biological Oxygen Demand (BOD) was measured in the laboratory by direct method, chloride by Argentometric method and

sulphate by turbidimetric method as described in APHA (2005). Fluoride was estimated by colorimetric method as described by Maiti (2001). The reagents used for the present study were analytical grade reagent (AR) and double distilled water was used for preparing various solutions. The quality assurance and quality procedure were also used as described in APHA (2005).

The temperature, pH and dissolved oxygen were measured at the sampling sites itself. The other parameters except iron were measured at Chemistry laboratory of Samtse College of Education, and at Department of Environmental Science laboratory, North-Eastern Hill University, Shillong. The concentration of iron was measured at Regional Sophisticated Instrumentation Centre, Shillong.

RESULTS AND DISCUSSION

The result of each parameter is analysed under the following subheadings:

Temperature

Temperature in aquatic ecosystem is one of the important parameters and has an impact on other water quality parameters such as dissolved oxygen concentration. The optimum temperature of water is essential for bio-chemical reactions of organisms living in it (Lalita ,*et al*. 2006).

During the study period water temperature was found to vary from 18.80˚C to 23.60˚C during pre-monsoon, 24.30˚C to 27.30˚C during monsoon and 16.30˚C to 20.90˚C during post monsoon. Normally water temperature fluctuates daily and seasonally. The water temperature gradually increased to 27.30˚C during monsoon and dropped to 16.30˚C during post monsoon. The seasonal variation in water temperature in all the sampling sites is represented in fig 2.

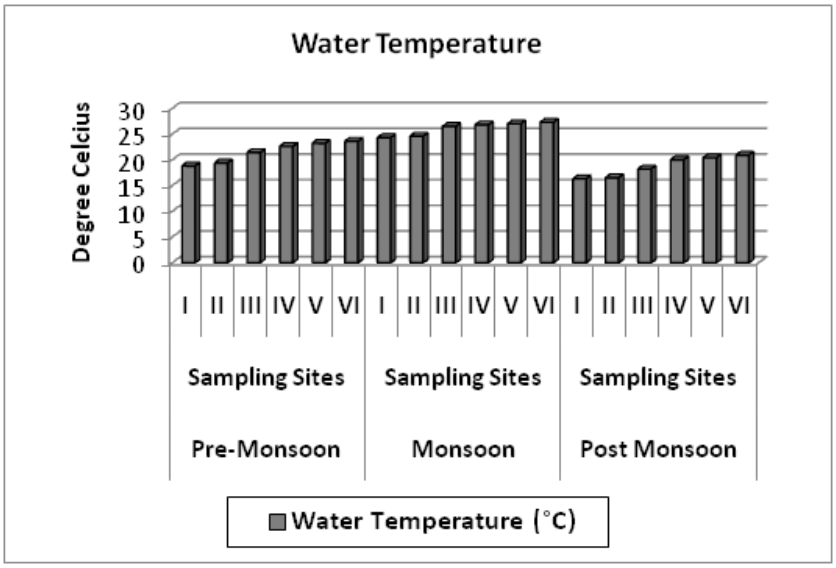


Fig 2. Bar graph showing seasonal variations in water temperature pH

The pH of an aquatic ecosystem is important because it is closely linked to the survival of aquatic animals. The pH values between 6.5 – 8.5 usually indicate good water quality. It was observed that the pH values of the water samples are slightly alkaline throughout the three seasons varying from 7.10 to 7.47 (fig 3) and these values are within the highest desirable limits prescribed by WHO and BIS. Hence, the pH values are found to comply with the standards for drinking water.

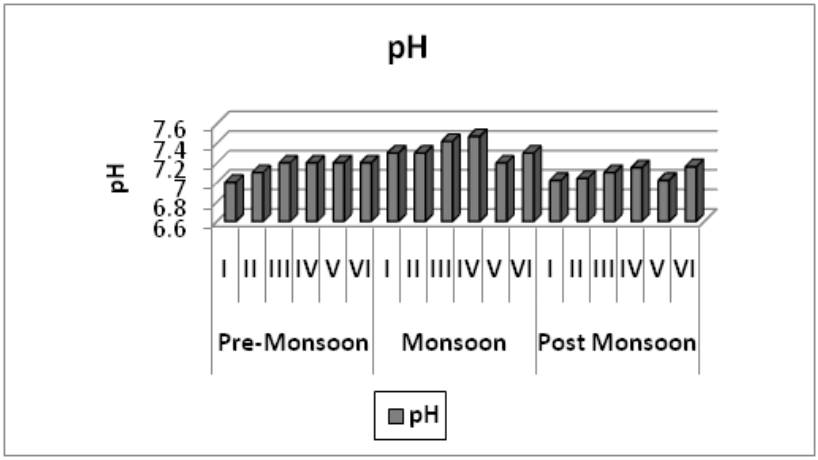


Fig 3. Bar graph showing seasonal variations in pH

Turbidity

The water bodies that have high transparency values generally have good water quality. The turbidity of water is mainly caused by the suspended and colloidal particles. The turbidity during pre-monsoon was within the permissible limits set by WHO and BIS ranging from 1.10 to 5.0 NTU. However, the turbidity during monsoon season was much higher than the permissible limits ranging from 25.20 to 65.20 NTU in all the sampling sites. The high turbidity values during monsoon could be due to excessive rainfall which causes flooding of streams and rivers. Vaishya and Adoni (1992) stated that the turbidity of water increases when rain water carrying suspended solids and effluents are mixed. During post monsoon the turbidity was within the permissible range of 2.50 to 4.60 NTU. The seasonal variation in turbidity of all the locations is represented in fig 4.

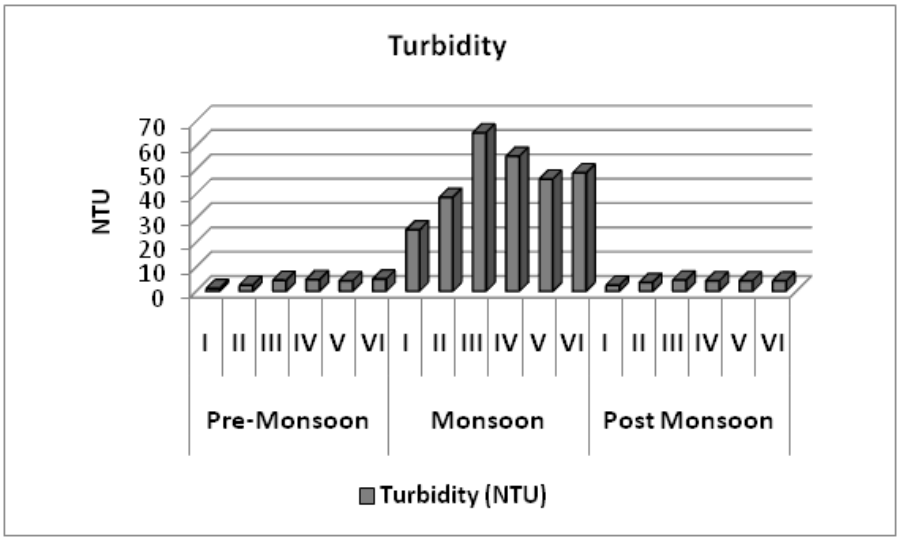


Fig 4. Bar graph showing seasonal variations in turbidity

Total Dissolved Solids

The total dissolved solid (TDS) gives quantitative measurement of ionic constituents dissolved in water. The presence of suspended and dissolved solids may affect water quality in a number of ways. The water with high suspended and dissolved solids are generally of inferior quality. A maximum limit of 500mg/L is permissible for drinking water. The TDS in all the sampling sites throughout the year was found within the maximum

permissible limit. A maximum value of TDS was found during monsoon season ranging from 33.23 to 145.40mg/L. The TDS concentration was found to be higher in monsoon, which may be attributed to greater solubility of ions at higher temperature. The variations in total dissolved solids during pre-monsoon, monsoon and post monsoon is represented in fig 5.

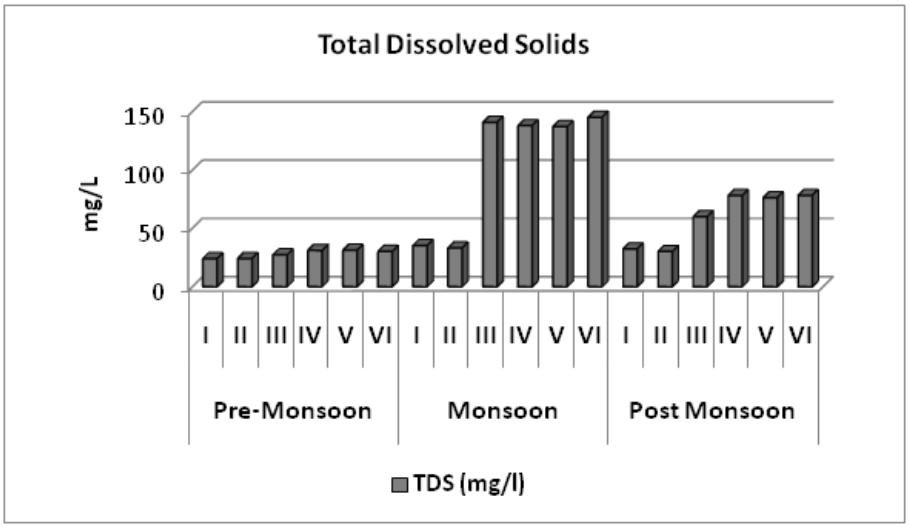


Fig 5. Bar graph showing seasonal variations in total dissolved oxygen

Dissolved Oxygen

Oxygen is needed for the metabolic activities of aerobic organisms and also it influences chemical reactions. For the healthy living of aquatic organisms the dissolved oxygen concentration should be higher than 3mg/L. The higher concentrations of dissolved oxygen in water usually indicate good water quality. The dissolved oxygen concentration in the study area was found consistently higher in the upstream forest area. The dissolved oxygen values ranged from 12.00 to 8.20 mg/L during pre-monsoon, 9.32 to 7.29 mg/L during monsoon and 11.32 to 5.80 mg/L during post monsoon (fig 6). The lower values of dissolved oxygen in the downstream could be due to the organic manure runoff from the agriculture field. Rukeh *et al.,* (2006) reported that dissolved oxygen concentration in water is usually depleted if organic matter undergoing biological degradation is present.

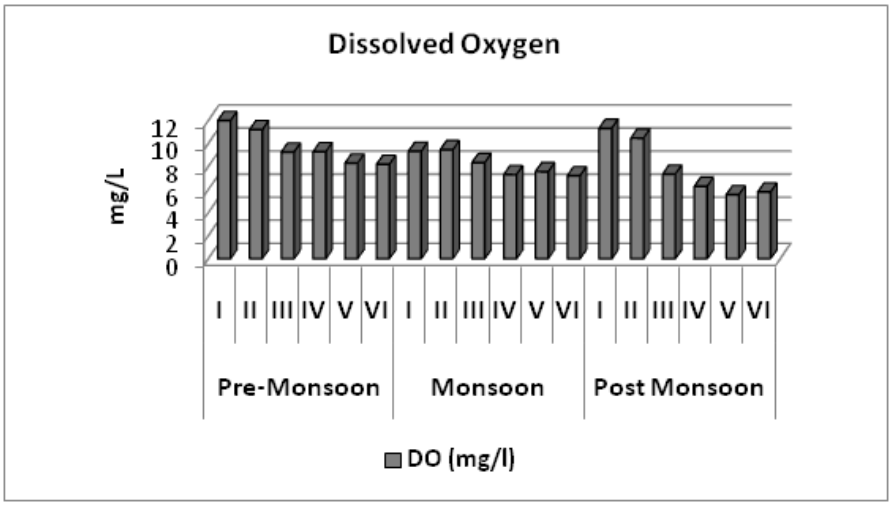


Fig 6. Graph showing the Seasonal variation in dissolved oxygen concentration

Total Hardness, Calcium and Magnesium Concentration

The total hardness of water is defined as the sum of the calcium and magnesium ion concentrations, both expressed as calcium carbonate, in milligrams per liter. The total hardness of all the water samples are within the permissible limits ranging from 38.30 to 49.30 mg/L during pre-monsoon, 24.50 to 49.23 mg/L during monsoon and 32.10 to 57.30 during post monsoon as calcium carbonate equivalent. The calcium and magnesium concentrations are found to be much lower than WHO maximum permissible concentrations of 100 and 150mg/L respectively. The variations in total hardness, calcium and magnesium in all the seasons are shown in fig 7.

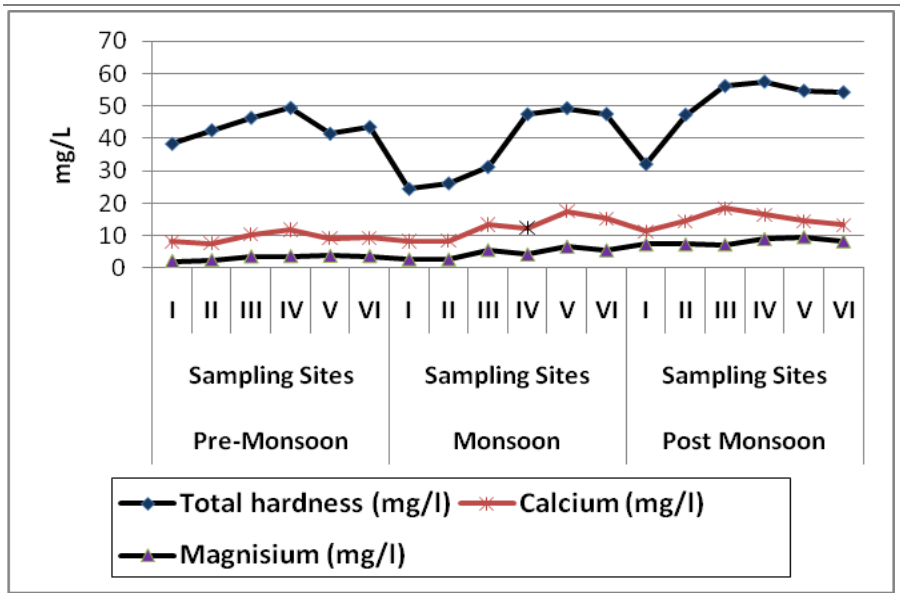


Fig 7. Graph showing the Seasonal variation in Total hardness, calcium and magnesium

Nitrate, Sulphate and Phosphate

The main source of nitrate and phosphate in water is from chemical fertilizers used in agriculture field (Muhibbullah *et al*., 2005). It is found that all the water samples analysed are free from nitrate, phosphate and sulphate pollution as the amount of nitrate varied from 0.11 to 2.62 mg/L and the sulphate concentration varied from 7.40 to 25.50 mg/L throughout the study period. The concentration of phosphate ranged from 0.02 to 0.35 mg/L in all the sampling sites. There is no maximum permissible limit set for phosphate concentration in drinking water. The concentration of nitrate and sulphate are within the permissible limits set by WHO and BIS. However, the slightly higher values of nitrate, sulphate and phosphate in the downstream as compared to upstream water indicate that agricultural activities are beginning to affect the quality of water. The nitrate concentration is much higher around agriculture field during monsoon and post monsoon as shown in fig 8.

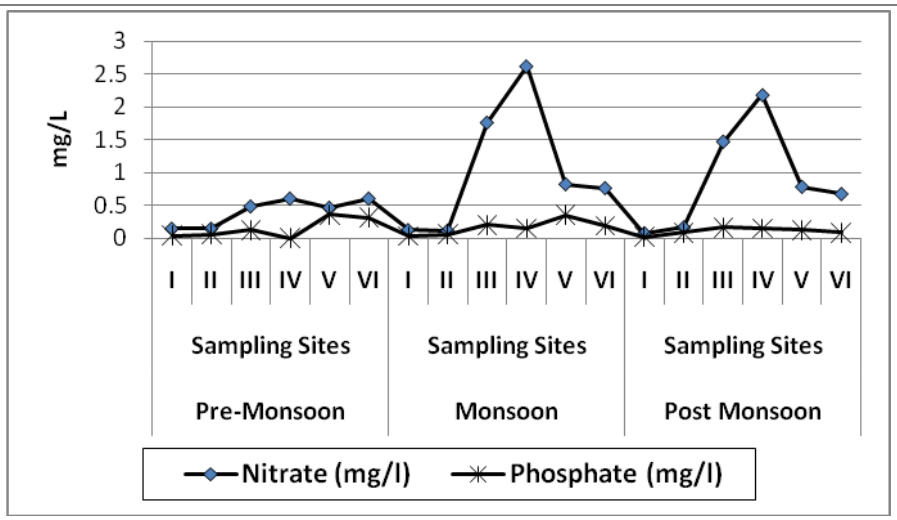


Fig 8. Graph showing the Seasonal variation in nitrate and phosphate Fluoride

Fluoride occurs naturally in water sources. Fluoride in water is derived mainly from the dissolution of minerals in the rocks and soils with which water interacts. The most common fluorine-bearing minerals are fluorite, apatite and micas. It is a well known fact that fluoride helps to prevent the early stages of tooth decay. The tooth decay occurs when bacteria that accumulates on the teeth breaks down sugars in food. In the process of breaking down sugars in food, bacteria release acids that dissolve the hard enamel of teeth. The bacteria can penetrate through the enamel causing tooth decay. Research findings recommended that the fluoride in drinking water at a concentration of 0.7 to 1.2mg/L is safe enough to prevent tooth decay. The fluoride prevents the acid produced by the bacteria from dissolving the enamel. As per WHO guidelines, when the concentration of fluoride in water is greater than 1.5mg/L it can lead to dental fluorosis and in extreme cases can cause skeletal fluorosis.

The permissible limit for fluoride content in drinking water as per the WHO and BIS standard is 1.5mg/L. All the water samples analysed through out the year showed fluoride content in the range of 0.40 to 1.20 mg/L which is lower than the maximum permissible limit as shown in fig 9. Therefore, the water samples are free from fluoride pollution.

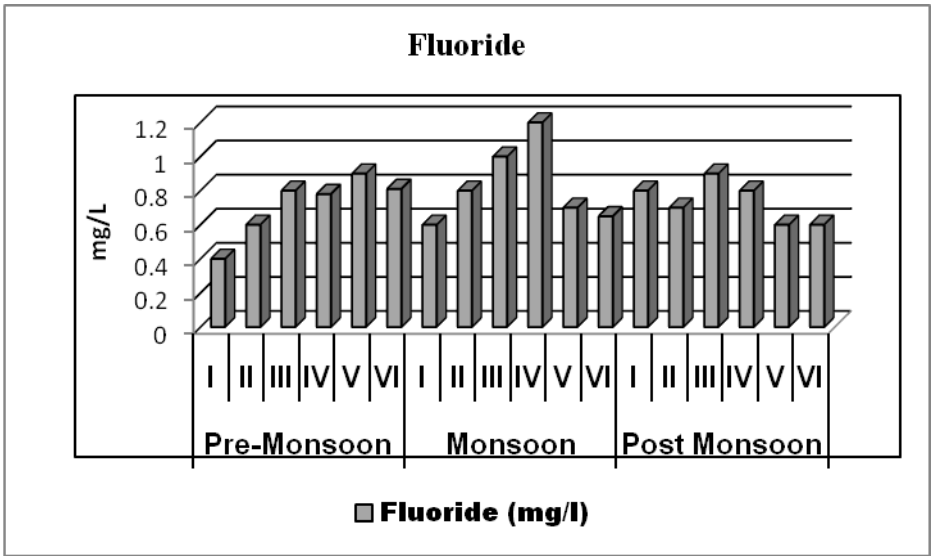


Fig 9. Bar graph showing the seasonal variation in fluoride Chloride

The chloride ions occur naturally in surface and ground water. A small amount of chloride is necessary for normal cell functions of plants and animals. The drinking water standards require chloride concentration not to exceed 250mg/L and for the protection of aquatic plants and animals it should be less than 600mg/L. The higher concentration of chloride is detrimental to water quality. The chloride may enter into surface water through rocks containing chlorides, agricultural runoff, industries, effluent wastewater and from road salting.

During the study period chloride concentration ranged from 3.45 to 5.28 mg/L during pre-monsoon, 6.24 to 8.12 mg/L during monsoon and 5.46 to 7.90 during post monsoon as shown in fig 10. The Bureau of Indian Standard has set 250 mg/L as the highest desirable limit for chloride concentration in drinking water.

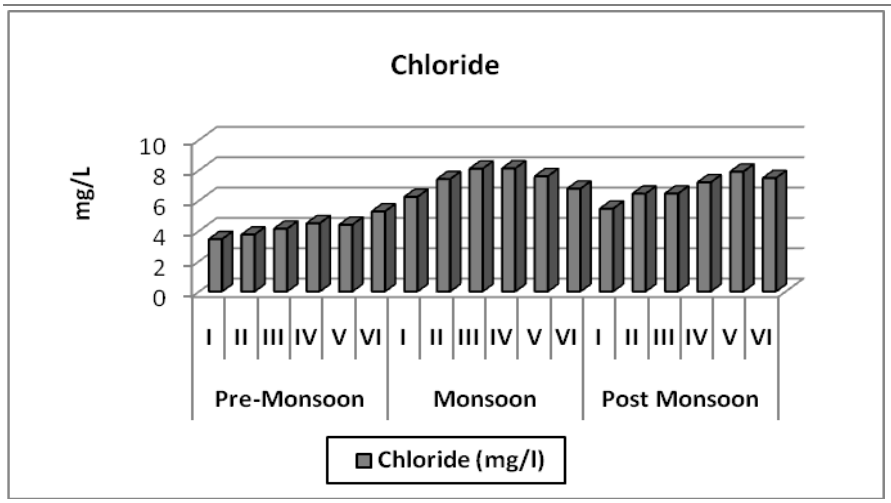


Fig 10. Bar graph showing the Seasonal variation in chloride concentration

Iron

Iron is an essential element in human nutrition. Iron is not considered hazardous to health. In fact, iron is essential for good health because it transports oxygen in blood. The permissible limit for iron in water which is 0.3 mg/L is based on taste and appearance rather than on any detrimental health effect. In some sampling sites the concentration of iron was found higher than the permissible limit. The concentration of iron ranged from 0.20 – 0.43 mg/L during pre-monsoon, 0.12 to 0.27 mg/L during monsoon and 0.16 to 0.42 mg/L during post monsoon as represented in fig 11.

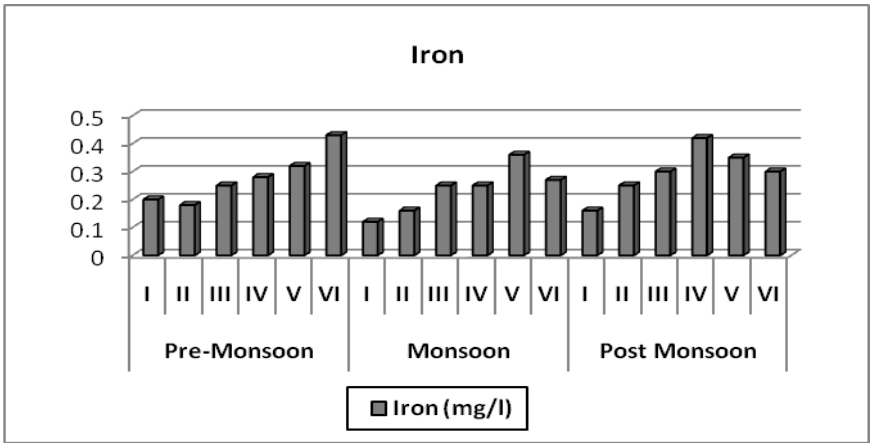


Fig 11. Bar graph showing the Seasonal variation in iron concentration

Biochemical Oxygen Demand (**BOD)**

Biochemical oxygen demand is a measure of the amount of oxygen removed from water by aerobic micro-organisms for their metabolic requirements during the decomposition of organic matter at 20˚C over a period of 5 days. The BOD values varied from 0.20 to 2.60 mg/L during pre-monsoon, 0.45 to 3.24 mg/L during monsoon and 0.20 to 2.45 mg/L during post monsoon. The higher values of BOD in the downstream of agriculture field can be attributed to the presence of decaying organic matter. Fig 12 clearly indicate that the BOD values in upstream is minimum as compared to downstream

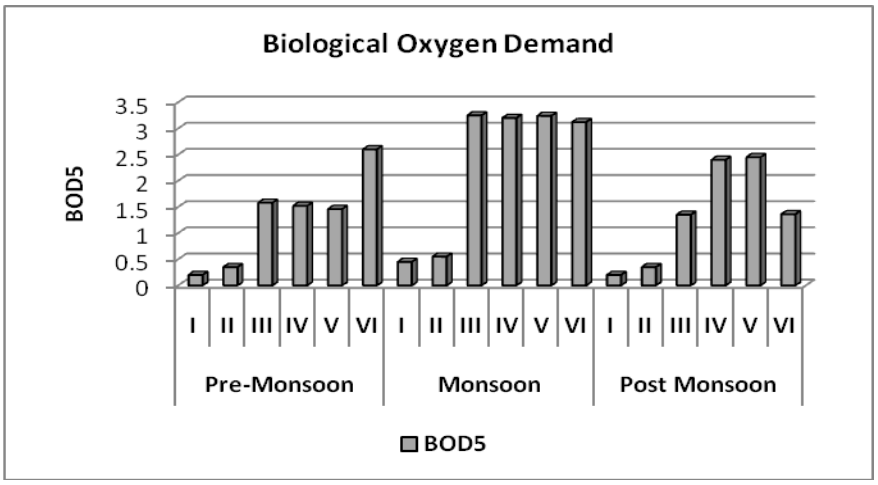


Fig 12. Bar graph showing the Seasonal variation in biological oxygen demand

There are no prescribed standard values for drinking water purposes suggested by WHO and BIS for parameters like electrical conductivity, alkalinity, phosphate and water temperature. Hence, no comparison could be made from the observed values. However, general conclusion may be drawn from the results. The electrical conductivity and alkalinity of water was found lower in sampling sites I and II as compared to rest of the sampling sites in the downstream.

CONCLUSION

The water samples collected upstream of agriculture field showed better quality than those collected downstream. The water in the upstream of the agriculture field have higher dissolved oxygen concentration, lower TDS, turbidity, BOD, electrical conductivity and water temperature as

compared to the downstream water. All the parameters studied are within the permissible limits set by WHO and BIS, except turbidity during monsoon and iron concentration. The decrease in dissolved oxygen concentration, increase in TDS, turbidity and BOD in downstream indicate that agricultural activities is beginning to effect water quality in and around the agricultural field. The effect is more during the farming season. This could be mainly due to the runoff from the agriculture fields. The study recommends educating farmers to control runoff from the agriculture fields.

On the whole water quality in and around the agriculture field is of good quality as most of the parameters studied are within the permissible limits of WHO and BIS.

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An analysis of household food demand in Bhutan

Chencho Dukpa[1] and Bart Minten[2]

ABSTRACT

In order to be able to better target food policy interventions in the near future, it is important to understand the present behavior of consumers in terms of what they eat, how much they eat and how these are impacted upon by changes in income and price. Analysis of the BLSS 2007 survey data reveals that the nominal monthly expenditures in 2007 were estimated at Nu 1328 per capita on food and Nu 1954 per capita on non-food. Food expenditures represent about 40% of the total expenditures of an average person in Bhutan. The richest households have per capita expenditure levels that are eight times as high than the poorest households. The richest households spend almost 4 times as much than the poorest households on food. Analysis within cereals revealed that maize and FCB rice combined account for 52% of the cereal basket of the poorest households compared to only 12% for the richest. Using an Almost Ideal Demand System (AIDS), income elasticities are estimated to be the lowest for the cereal groups (0.328). The highest income elasticity is for the 'other food' category (0.780). Assuming a 2% and 4% annual GDP growth, we project a 62% and near 100% increase respectively in total food demanded in 2030. Although cereals will remain very important (81% growth), the fastest growth in demand will be for 'other food' (172%), dairy (110%), meat (116%) and fruits (106%).

KEYWORDS: Food demand analysis, income and price elasticity, projections

INTRODUCTION

Different shocks such as droughts and floods as well as global price changes for fuel and other internationally traded goods might have an important impact on an economy and on household income. In periods of economic reform, economic factors such as exchange rate fluctuations and levels of taxation might also affect prices and incomes. Changes in

[1] Deputy Chief Research Officer, Council of RNR Research of Bhutan
[2] Senior Researcher, International Food Policy Research Institute

prices and income due to these factors influence the overall food consumption levels of poor households. However, it is often not clear to what extent they are affected by these events and what interventions might be needed to help them.

The reaction of households to such shocks can be predicted and quantified through economic parameters that are called 'demand elasticities'. These demand elasticities are important to know for those stakeholders who want to anticipate and alleviate the negative impact on the economy as a whole and on vulnerable households in particular. They are thus often used in economic models that simulate the impact of sectoral and macro-economic policies. A better understanding of demand can potentially further be used to better target food subsidies towards the poor. An ideal commodity for targeting is one that is consumed in large quantities by the poor and little by the others. A better understanding of demand can also further help to predict future demand of food products in different scenarios of income growth.

This study on food demand in Bhutan has several objectives. First, it aims to better understand the patterns of food consumption. Second, it will estimate demand elasticities and examine impact of changing income on food consumption. Third, it will make projections about future changes in food consumption.

MATERIALS AND METHODS

This study used the survey data of the Bhutan Living Standard Survey 2007, hereon to be referred as BLSS 2007, of National Statistics Bureau (NSB) of Bhutan who had conducted a nation-wide survey of households from March to May 2007.

In this analysis, food consumption patterns are presented by four important factors that might influence these patterns, i.e. consumption quintiles, urban versus rural areas, region and remoteness. First, consumption quintiles were constructed by NSB (2007a) based on the sum of all goods and services purchased, consumed from own production and received as gifts. All these goods and services were converted in Ngultrum values and aggregated as to obtain monthly household and per capita expenditures (NSB, 2007a). Such expenditure measure is commonly used as a good indicator to reflect the welfare of households

and individuals. Second, urban-rural areas were used as commonly defined by the government. Third, four regions were distinguished: the South (the Dzongkhags of Samtse, Sarpang, Tsirang), West (the Dzongkhags of Chhukha, Gasa, Haa, Paro, Punakha, Thimphu, Wangdue), Central (the Dzongkhags of Bumthang, Dagana, Trongsa, Zhemgang), and East (the Dzongkhags of Lhuntse, Monggar, Pemagatshel, Samdrupjonghkar, Trashigang, Trashiyangtse). Fourth, remoteness terciles were created based on a measure of the time needed to get to the nearest tarred road.

RESULTS AND DISCUSSION

Consumption patterns

Overall and non-food consumption

Table 1 shows per capita expenditures across consumption quintile, area, region and remoteness tercile. Overall, it is estimated that the richest quintile has expenditure levels that are eight and seven times as high than the poorest quintile in nominal and real terms respectively. These differences between the richest and the poorest quintile are less for food expenditures. However, the richest quintile still spends almost 4 times as much than the poorest quintile on food. The share of food versus non-food in total consumption decreases thus significantly from the poorest to the richest quintile, as would been predicted by economic theory: The poorest quintile spends 62% of their total expenditures on food; this compares to only 31% for the richest quintile.

We also note significant differences of food expenditures by area. Average expenditures are more than twice as high in urban areas compared to rural areas. Food expenditures make up 34% of total expenditures in urban areas. This compares to 46% in rural areas. This higher food share in rural areas partly reflects the lower overall consumption levels as food shares decline with higher welfare and the population in rural areas are in general poorer than in urban areas. As found by the NSB (2007b), the Western region is the most prosperous in Bhutan while the Eastern region is the poorest: real total expenditures in the Western region are almost twice as high as in the Eastern region. Remoteness is also shown to be a very important factor in explaining total as well as food expenditures levels.

Table 8. Food and non-food expenditures

	Per capita expenditures (Nu/month)				Share in total (%)	
	Food	Non-food	Total	Total-real	Food	Non-food
Consumption quintile						
Poorest	533	315	848	802	63.1	36.9
2nd quintile	806	575	1381	1273	58.5	41.5
3rd quintile	1067	930	1997	1812	53.6	46.4
4th quintile	1421	1569	2991	2630	47.7	52.3
Richest	2233	4864	7097	5602	35.0	65.0
Area						
Urban	1851	3528	5379	4403	40.6	59.4
Rural	1103	1276	2380	2035	53.6	46.4
Region						
South	1094	1284	2378	2177	51.6	48.4
West	1572	2867	4439	3580	43.0	57.0
Central	1310	1639	2949	2344	53.9	46.1
East	1124	1144	2268	2022	56.7	43.3
Remoteness						
Closest tercile	1646	3180	4826	3930	41.5	58.5
Medium tercile	1276	1612	2888	2446	50.9	49.1
Most remote tercile	989	835	1824	1630	58.5	41.5
Bhutan overall	1328	1954	3282	2748	49.7	50.3

Source: Own calculations based on BLSS, 2007

Food consumption

Table 2 shows the composition of food consumption by consumption quintile, by area (rural/urban), by region, and by remoteness. For the analysis in this document, we distinguish nine food categories: (1) cereals (including different rice categories, wheat, maize, ata, other flour, and a negligible amount of pulses); (2) dairy (milk and processed milk products); (3) fish and meat; (4) fruits; (5) vegetables; (6) beverages (coffee, tea, alcoholic beverages, juices, water and carbonated drinks); (7) cooking oils; (8) spices, seasonings and pastes; and (9) 'other foods'

(food taken outside the home; noodles; confectionery; biscuits; tobacco and doma).

Table 2. Consumption levels of different food categories (Nu/month/cap - nominal)

	Cereals	Dairy	Fish/ meat	Fruit	Veget-ables	Beverages	Oil	Spices	Other food
Consumption quintile									
Poorest	134	79	48	17	55	52	32	42	52
2nd quintile	185	129	77	25	82	72	45	60	88
3rd quintile	217	177	108	37	106	87	55	75	145
4th quintile	238	234	160	58	144	106	66	94	254
Richest	301	351	265	105	224	152	92	144	490
Area									
Urban	215	268	235	96	200	127	76	114	451
Rural	231	189	109	36	105	89	56	80	144
Region									
South	206	152	119	50	110	97	55	66	203
West	233	253	188	75	165	99	68	105	328
Central	268	244	137	39	114	124	65	94	161
East	213	180	107	33	109	97	57	81	148
Remoteness									
Closest tercile	229	256	199	79	177	116	71	108	349
Medium tercile	232	209	135	51	127	96	61	87	218
Most remote tercile	214	161	94	27	86	86	52	70	115
Bhutan overall	226	213	147	54	133	100	62	90	236
As % of total food	17.91	16.85	11.64	4.31	10.58	7.96	4.91	7.12	18.73

Source: Own calculations based on BLSS 2007

Food consumption patterns differ significantly over consumption quintiles (as also seen in other countries): when consumers get richer, they shift away from grains and consume relatively more high-value products such as fruits and vegetables, dairy products, meat and fish as well as more

processed food for convenience.[1] While expenditures on cereals more than double (2.25) between the poorest and the richest quintile, they however increase almost tenfold (9.4) for other foods, fourfold (4.4) for dairy products, fivefold (5.5) for fish and meat products, sixfold (6.2) for fruits, and fourfold (4.1) for vegetables.

The Western region has significantly higher food expenditures than the others. Cereal consumption is relatively less important and represent only 17% of total food expenditures. This compares to 22% for the other three regions. Dairy consumption is relatively and absolutely higher in the Central (244 Nu/cap/month) and the Western region (253 Nu/cap/month) compared to the East (180 Nu/cap/month) and the South (152 Nu/cap/month). The consumption of 'other foods' is relatively high in the West and the South. Fish and meat, fruits, vegetables, cooking oils and spices all show rather stable shares in the total food basket over regions.

Urban consumers have significantly higher food expenditures, almost twice as high. They also have a different composition of their basket and consume significantly more of 'other food', often food taken away from home.

Similar patterns as in the urban-rural divide are seen, i.e. a growing importance of 'other food' and the declining importance of cereals for the closest tercile compared to the most remote tercile.

Cereal consumption

Given the importance of cereals in the policy discussion on food security in Bhutan, we look more in depth at the importance of the different products that make up this category. The BLSS of 2007 distinguishes six types of rice: Bhutanese rice, bhog rice, fine rice, FCB rice, other rice, and processed rice (especially 'zaw', 'sip'). FCB rice is the rice that is sold by the Food Corporation of Bhutan in shops that are widely present all over the country. While FCB used to receive subsidies from the government to assure a pan-territorial pricing strategy for rice, it however in recent years became self-reliant and it has moved away from this policy. Bhog, fine and FCB rice are all mostly imported rice. Under

[1] This shift is more commonly known as Bennett's law (Bennett, 1941).

cereals, we also include maize, wheat, and as a last category a combination of tengma, popcorn, ata, maida and other flour.

Table 3 shows importance of the different cereals in total expenditures on cereals overall, by consumption quintile, by area, by region, and by remoteness. We see overall that rice accounts for 80% of the expenditures on cereals while the remainder is made up of maize (9.8%), the ata/flour category (10%) and wheat (0.7%). Note also that maize and FCB rice are important cereal crops for the poorest quintile: Combined, they contribute to about 52% of the expenditures on cereals by the poorest quintile. This compares to only 12% for the richest quintile. FCB rice and maize represent 29% and 23% respectively of the consumption of the poorest. The comparable numbers for the richest quintile is 10% and 2%. Instead of maize and FCB rice, the rich prefer to eat Bhutanese rice (25% of their cereal expenditure), fine rice (23%) and processed rice (13%).

Table 3. Consumption levels of different cereals (Nu/month/cap - nominal)

	Bhut-anese rice	Bhog rice	Fine rice	FCB rice	Other rice	Proce-ssed rice	Wheat	Maize	Pop-corn, ata, other flour
Consumption quintile									
Poorest	30	1	13	36	9	4	1	28	7
2nd quintile	52	2	23	39	12	9	1	28	11
3rd quintile	68	4	31	40	14	13	2	22	15
4th quintile	73	4	44	39	13	18	2	13	19
Richest	90	12	63	29	19	31	2	7	31
Area									
Urban	29	9	63	29	17	24	0	2	27
Rural	83	4	27	39	12	14	2	25	14
Region									
South	39	11	36	31	26	9	1	21	15
West	82	5	47	26	14	23	2	3	21
Central	101	6	31	45	8	21	5	22	18
East	50	2	29	51	9	11	0	37	17
Remoteness									

Closest tercile	54	8	52	31	16	22	1	8	23
Medium tercile	79	5	33	36	16	16	2	16	17
Most remote tercile	66	2	27	43	8	10	2	34	13
Bhutan overall	67	5	38	36	14	17	1	18	18
As % of total cereals	31.03	2.55	17.74	16.80	6.49	7.83	0.69	8.39	8.47

Source: Own calculations based on BLSS, 2007

Tables 3 also highlight other points to note. The consumption of Bhutanese rice is especially important in the Western and Central regions where they represent 30% of all cereal expenditures. FCB rice and maize are the most important in the Eastern part of the country: FCB rice and maize represent in this region 28% and 20% respectively of total cereal consumption. The consumption of fine rice is most important in the South and the West.

Rural areas consume significantly more Bhutanese rice. Bhutanese rice represents 30% of the total cereal consumption in rural areas. This is only as high as 12% in urban areas. Maize consumption is almost exclusively a rural phenomenon as less than 1% of the cereal budget in urban areas is spent on this. FCB rice is also relatively more important in rural areas (20%) than in urban areas (15%). We see little differences for overall cereal expenditures by remoteness tercile. However, the composition differs significantly as more remote households rely significantly more on maize and FCB rice.

Demand Analysis

This section is concerned with estimating income and price elasticities of demand. We estimate them based on an approach called the Almost Ideal Demand System (AIDS) developed by Deaton and Muellbauer (1980). Unlike earlier models (e.g. Working model of Working (1943)) which suffer from certain disadvantages in that they do not follow the theoretical constraints of demand analysis related to aggregation, homogeneity, and symmetry, the AIDS model is considered very robust and is thus widely used in demand analysis. Its popularity is driven by the fact that it is very general and does not require explicit specification of the utility function; that it is relatively easy to estimate given that it is linear, and that it

conforms to economic theory. To perform such estimation in practice, we use a Linear Approximation of the Almost Ideal Demand System (LA/AIDS):

$$w_i = \alpha_i + \sum_{ij} \gamma_{ij} \ln p_i + \beta_i \ln y/P + \sum \varphi_k Z_k$$

where w is the budget share for a commodity i, p is a set of commodity prices going from 1 to n, y is per capita income (or per capita expenditure), P is a price index[1]*, Z is a set of k household characteristics*[2]*, and* α_i, γ_{ij} , β_i, *and* φ_k *are parameters to be estimated.*

To obtain the prices, we divided expenditures by quantities for a particular food group for a particular household. The median price in the village was then calculated and used in the analysis.

The equation thus links budget shares of different foods with prices of the food itself, with prices of other foods, and with total food consumption levels. To assure that the system respects the constraints imposed by economic theory, the system is estimated under three types of constraints, i.e. (a) Additivity $\sum_i \alpha_i = 0$; $\sum_i \beta_i = 0$; $\sum_i \gamma_{ij} = 0$; (b) Homogeneity: $\sum_j \gamma_{ij} = 0$; and (c) Symmetry: $\gamma_{ij} = \gamma_{ji}$

A food expenditure elasticity can then be estimated from the equations as follows:

$$\eta_i = 1 + \beta_i / w_i$$

To be able to estimate the model, we estimate a system of equations of n-1 equations, an equation for each good except for the 'other food' items. The calculation of the elasticities for this group is done as a residual from the other groups.

[1] A linear approximation of the translog price index $\ln(P) = \alpha_0 + \sum_i \alpha_i * \ln(p_i) + (1/2) * \sum_i \sum_j \ln(p_i)* \ln(p_j)$ can be done by using a corrected Stone price index (P*) defined as $\ln(P^*)=\sum_i w_i * \ln p_i$ (Asche and Wessels, 1997). Prices have to be normalized to assure a right calculation of the standard errors. To do so, all prices were divided by its mean price before the estimation of the system.

[2] In our estimation, we included household size, a dependency ratio, gender of the head of household, age of the head of household and a dummy to specify whether a household is in urban or rural areas.

To get at the complete income elasticity, the food expenditure elasticity (the elasticity that measures the impact of the increase in total food expenditures on quantities consumed) is multiplied with a food expenditure – total income elasticity (the elasticity that measure the effect of changes in total income on food expenditures).[1]

Table 4 shows the results for the estimations of the income elasticities. Income elasticities are the lowest for the cereals groups: they are estimated to be 0.321, i.e. a doubling of the income would lead to an increase of consumption of cereals by 32%. Similar low income elasticities are obtained for cooking oil (0.332), spices (0.355) and vegetables (0.379). The highest income elasticity is for the tobacco and other food category where a doubling of total income would lead to an increase in spending on this category of 76%. Other high income categories exist for dairy (0.515), fish and meat (0.518), fruits (0.469) and beverages (0.464).

Table 4. Income elasticities of different food categories

Food category	**Share in food budget**	**Income elasticity**
Cereals	0.201	0.321
Dairy	0.172	0.515
Fish and meat	0.112	0.518
Fruits	0.041	0.469
Vegetables	0.108	0.379
Beverages/tea/coffee	0.084	0.464
Oil	0.054	0.332
Spices	0.075	0.355
Other food	0.153	0.765

*Food-total expenditure elasticity = 0.472
Source: Own calculation based on BLSS 2007

[1] The last equation was estimated as part of a Seemingly Unrelated Regression (SUR) model.

Demand projections

Using the estimated income elasticities in combination with per capita income assumptions, one can make inferences on food demand projections for different products using the following expression:

$$D_1=D_0*(1+y*\eta)^t$$

where D_1 is per capita demand in some year in the future, D_0 is demand in the base year (the year of the survey), y is the assumed growth in per capita income, η is the estimated income elasticity of demand for the commodity, and t is the number of years between the base and the projection year.

Let us project demand under three scenarios of per capita income growth: low growth (2%), medium growth (4%), and high growth (6%). The results are given in Table 5.

Table 5. Projected per capita demand growth under different income growth scenario (kg/cap/yr)

	Product category								
Year	Cereals	Dairy	Fish/meat	Fruit	Vegetables	Beverages	Oil	Spices	Other food
2% annual per capita income growth									
2007	132	26	13	31	84	22	10	21	9
2010	134	26	14	32	86	23	10	22	9
2015	139	28	15	34	89	24	10	22	10
2020	143	29	15	35	92	25	11	23	10
2025	148	31	16	37	96	26	11	24	11
2030	153	32	17	39	100	27	12	25	12
4% annual per capita income growth									
2007	132	26	13	31	84	22	10	21	9
2010	137	27	14	33	88	23	10	22	9
2015	146	30	16	36	94	25	11	24	11
2020	155	33	17	40	102	28	12	25	13
2025	166	37	19	44	110	31	13	27	15
2030	177	41	21	48	118	33	13	29	17
6% annual per capita income growth									
2007	132	26	13	31	84	22	10	21	9
2010	139	28	15	34	90	24	11	23	10
2015	153	33	17	39	100	27	12	25	12
2020	169	38	20	45	112	31	13	28	15
2025	186	44	23	52	126	36	14	31	19
2030	204	51	27	59	140	41	16	34	24

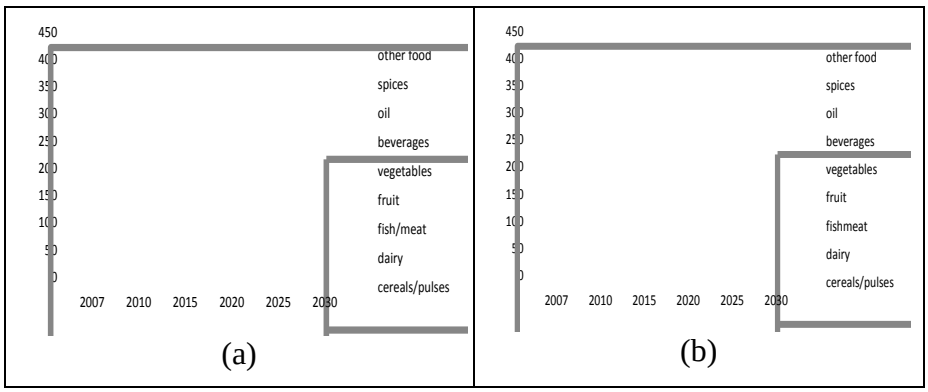
Source: Own calculations based on BLSS, 2007 and Populations projections Bhutan 2005-2030

If Bhutan would be able to sustain a per capita growth rate of 6%, the per capita consumption of cereals in 2030 would be as high as 204 kgs per capita, more than 50% higher than its current level. Per capita dairy consumption would almost double in 2030 compared to 2007 while the 'other food' category would almost triple (although it is starting from a low base). On the other hand, when incomes would grow on average by 2% a year, growth rates in consumption are much lower and are estimated over the period 2007-2030 at 16% for cereals, 23% for dairy products and 31% for meat and fish. In the case of 6% growth, cereal consumption would be 51 kgs higher in 2030 than in the case where only a 2% growth rate would be achieved. Given the lower consumption levels of other products, the difference in quantities for different growth rates is lower. However, the difference is still as high as 40 kgs in the case of vegetables and 20 kgs in the case of fruits.

To arrive at total food or food commodities that would be demanded by the country's population in a certain year, we simply multiply the per capita demand figures by the population projected in that year. According to NSB (2007c), the population of Bhutan is expected to grow by almost 40% by 2030, implying an average annual growth rate of 1.4%.

Figure 1 shows the projections of different food commodities under different income growth scenario at the national level. Assuming a 4% per capita income growth, it is projected that the total food quantity demanded by Bhutan would almost double by 2030. This compares to a 62% growth in total food consumed in the case of a 2% per capita income growth. The importance of different food sectors will also change. The cereals food category will stay still the most important of all food categories, although it has the lowest growth rate: in the case of a 4% per capita income growth, it is projected to grow by 80% between 2007 and 2030. The fastest growing food categories during that same period are 'other foods' at 154%, dairy products at 112%, fish and meat at 117% and fruits at 108%.

Figure 1. Projected food demand in Bhutan in 1000 tons: assuming 2% (a) and 4% (b) annual income growth per capita.



CONCLUSION

Poorer households have significantly different consumption baskets than richer households. Poorer households rely significantly more on maize and FCB rice for their cereal consumption: both products account for more than half of the expenditures on cereals. Cereals have in general much lower price and income elasticities than other food categories, indicating that consumers shift away from these crops when they become richer. Demand for most food items are projected to increase greatly by 2030.

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Extension service for better rural livelihood

BN Bhattarai[1]

ABSTRACT

The study on the extension system as a means of rural livelihoods improvement is on the whole to assess native extension service in the context of rural livelihood enhancement through dissemination and adoption of appropriate technologies with reciprocal clientele support coordination mechanisms. The scope of this study is limited to a synopsis of insight acquired from association in the extension service delivery, and scanning desired experiences to devise an extension service focused to potential socio-economic development based on technical interventions.

The extension service in Bhutan dates back to 1970s and was the first frontline field oriented rural based agriculture development service in the country. The essence of the extension service was recognized a link to dialogues between the rural communities and the policy makers. The objective of the extension service then was to connect the field situations and the rural people with the relevant functionaries through extension information and education leading to food self sufficiency. The mandates of the extension personals were to work closer with the rural people to address farming issues and correlate with other relevant agencies. The major roles to farming practices were concerted to increase crops production through supply of high yielding varieties of seeds and seedlings, improvement of irrigation infrastructure, land and soil fertility development supported with deliverance of improved agriculture inputs such as fertilizers, seeds, seedlings and plant protection chemicals. The conduit in the technology transfer was favored by organizing farmers' trainings, visits, meetings and conducting field demonstrations. In the later part of the FYP, the additional function was processing of payments and forms on agriculture subsidy and rural credit loans respectively.

[1] Principal Extension Officer, Department of Agriculture, MOAF, Thimphu

The extension structure being only the rural based agriculture development service, ever-since has been under pressure to meet persistently increasing demand for food productions. The transformation of extension has therefore been inevitable to address emerging challenges harmonizing aspirations of the rural communities and the Government agencies. Therefore a series of institutional reforms were undertaken in extension which barely kept pace coping up with rapidly rising challenges of low productivity and un-attractive farming scheme for the prospecting farmers. The understanding of these limiting situations was conscious unconsciously of where our farmers live, how they subsist and what they desire lacked fine-tuning in the policy and strategy instruments. A harmonized holistic functional linkage with effective coordination mechanism attuned to the multiplicity of farming system to promote and instil curiosity among the relevant stakeholders towards effectual extension service with a client based, agro-ecological based, and commodity based, participatory extension service, a way-forward for extension system in Bhutan.

K**EY WORDS:** extension service, policies, food security, rural income, institutions transformation, reorganization, support mechanism, approach, technologies, inputs, capacity development, coordination & extension officers

BACKGROUND

Bhutanese extension system since 1970s has been traditionally a public funding service for agriculture development in the country with an objective "helping farmers to help themselves" to facilitate in the effort to improve their livelihoods by increasing productions, cash income and preserving pristine farming environment. A wide coverage of all farming communities and versatile field activities with bare minimum of extension staff, a top-down blanket extension approach was an option, and the achievement of the extension service was supply based providing inputs, training the farmers, conducting demonstrations and visiting farmers or farms. The extension service nevertheless remained only the viaduct to connect rural communities, policy makers and all other pertinent agencies for rural agriculture development in the country.

The 5th FYP saw a shift in the extension approach that focused on area based agriculture potentials and perceived field constraints. The extension

efforts were concentrated to land development through terrace making, contour bunds making, soil fertility development through composting, compost shed construction, plant protection and irrigation programs. The implementation of these programs was tied up with one or other forms of subsidy payments to the farmers. The achievement in those times when compared today can be rated one of the best in light of focus and potential based extension approach, yet there had been some limitations. The extension officers having to look after more than one Gewogs and or stationed far in the remote locations rarely visited the activity sites for verifications or backstopping the farmers. The extension officers were required to verify activities physically for subsidy payment to the farmers but the field verifications were done in their offices resulting land development activities such as dry land claimed to have terraced in to wetland never converted physically but the payment of subsidy released and the record in the *sathram* updated. Further, the free supply of plant protection chemicals encouraged the farmers to use the chemicals unreasonably.

The Agriculture extension and irrigation service was decentralized in 1981 that comprised agriculture sectors in the Dzongkhags. The Rural Credit Scheme of the BDFC was given to be an additional mandate of the sector. The Dzongkhags Agriculture sectors were manned with one plant protection supervisor each which later merged in the regular Dzongkhags extension system. The irrigation sections in the Dzongkhags agriculture sectors were run by qualified engineers with policy guidance and support from the Irrigation Division of the Department of Agriculture. The very purpose of professional services got diluted now after it is carved out to form Dzongkhags Engineering Cells associated with the Ministry of Works & Housing. The extension service in the Dzongkhags gradually got added with non-extension jobs such as *chadi*, subsidy payments, rural credit loan processing & disbursement, sale proceeds, stores and inputs. The role of the parent department was imprecise in the decentralized extension service system. The technology dissemination and facilitation role of the extension officers in the process divulge to other added responsibilities which required limited professional interactions, coordination and backstopping mechanisms.

The subsidy payments for inputs were selectively phased out during 7 FYP while transportation cost of the inputs up to the nearest motor road points continued to be borne by the Government. The Sales & Service

Representatives the then Commission Agents were established to deal with cash and carry on all agriculture inputs. The plant protection chemicals by its toxic nature remained with the National Plant Protection Centre for supply on demand with cash and carry system. This arrangement was made to relieve the extension officers from dealing with sale proceeds, and to focus more on technologies transfers through farmers' trainings, study tours, demonstrations and crops promotional program. The crops promotional program was introduced to substitute cash and carry system for inputs, and aimed to popularize released varieties of seeds and seedlings in the farms. The extension approach and the results respond to the reorganization were insignificant as a result the extension service continued in the same manner that the vocal and the influential farmers derived better extension service than the resource poor farmers.

The process of dynamism in extension service is unavoidable in light of the changes and challenges of increasing demand of the rural communities and the Government agencies. In search of a coping mechanism impelled a series of transmutations through realignment but the very essence for desired change in extension approaches, methodologies and the National Extension Policy have not sufficiently responded to these institutional adjustments. The RNR extension service of the DRDS was indeed aimed to serve the farming community jointly with a holistic approach but the very intention botched to dilution trends of subject matters in the RNR extension services coupled with duplication of efforts. The restructuring exercise in 2003 created CoRRB with its mandate for all research programmes in the country. This reorganization delineated research from extension of the same profession creating an unprecedented gap on information sharing and generation of economically viable and adoptable technology. Towards narrowing down this gap and to create tangible impacts in the field, Research Outreach Programme (ROP) was initiated through the research centers to show case technologies. Besides positive contributions of the ROP, there were also criticisms often shared by the extension officers at different forums in the past that the research dominated extension and the ROP encouraged resource concentration leading to duplication of efforts with few households benefitted, and on the contrary the majority of the households depended on general extension service often with limited resources. The complexity of rural settings and diverse agriculture situations in the

country made itself difficult to cope up with the emerging needs by only the extension service with all-round mandates.

Methods and Materials

The past and the present extension service delivery and approaches have been studied in terms of service effectiveness and outputs in the improvement of rural livelihood.

The linkages and the interactions frequency on information sharing, capacity building and formulation of implementation guidelines have been reviewed as well feedback from among extension officers and allied central and research programs were noted. The farming technologies disseminations and adoption assessed through field visits, meetings and workshops with the farming communities, researchers and the extension officers.

Design and Treatment

At least part took actively in 13 rounds of field visits, participated in 26 workshops and 21 discussions meetings with the farmers, extension officers, officials from area development projects and researchers. A minimum of 18 Dzongkhags and 48 Gewogs visited and feedback recorded on the status of extension service delivery from 2003 to 2009. The information sharing, gathering and studies conduct was a blend of formal, informal and open ending type.

The feedback were synthesized and compiled selectively to fit into this article. To be more specific, the important events as a source of data have been the annual review & planning workshops in the 6 project Dzongkhags between 2005-2009, draft document strategy presentations on commodity development for all the 20 Dzongkhags between 2004 to 2007, annual research-extension review and planning workshops at Lingmithang, Jakar, CNR the then NRTI Lobesa from 2004-2007, departmental extension meeting in May 2008, Chuzagang rice commercialization since 2008 and video footages development on extension field activities during 2008-2009 including the feedback on the draft presentation “enhancing agriculture extension service” during agriculture conference at Gelephu in Dec 2009. All the above information was compiled and analyzed taking into account the observations and the

experience of the author in the field of agriculture research and extension service.

RESULTS AND DISCUSSIONS

Present state of extension service in Bhutan

The past experiences showed that there is a need to synchronize relevant research and extension professions under the same line of command to address functional gap existed in the RNR system.Thus, the 2009 restructuring exercise supported realignment of Research Programs to the respective parent Departments in accordance to relevance of the subject matters. An appropriate institutional and functional mechanism prompts to streamline duplication of efforts, coordination mechanisms and technology generation to inculcate greater participation of the target groups in technology adoption process. The status of extension service till date continued with the concept of reaching all farmers in all areas irrespective of program potentials and the benefits derived for the farmers. A multiple activities under extension service added further workload of the extension officers to create tangible field impacts in the Gewogs. What remained unanswered today is the rationale on Bhutanese extension service still longing for desired impacts and to be cherished by the rural people.

The agriculture extension provides service to a large number of small farms and subsistence farmers comprising 69% of the total population with limited land holdings, small family labor and inadequate capital. The extension services objectively aim to apply appropriate methodologies and extension tools to augment adoption of improved practices for sustainable farming and increased crops productions. In contrast, the extension service providers still lack desired exposures and know how on extension processes and methodologies bearing in mind that extension deals with rural people, their culture, socio-economic and the local resources to assess and identify desired activities and methodologies to showcase technology and persuade adoption. The farm management economic principle is yet to find its just role in the extension service as a motivation factor for technology adoption by the farmers.

The present state of extension service in Bhutan is summarized as follows:

- The extension officers in the service before 90s have a tendency to continue the same extension reach as it used to be in those times despite situational changes and expectations today. The precedence has persuaded the new comers to follow footprints of the seniors.
- The methodological concept and strategy in the FYP programs is vague for implementation of extension program. There is a need for a clear implementation strategy for extension service delivery linking to real field situation with anticipated impacts on the interventions.
- The extension officers are multi-tasking which bottlenecks focusing in the planning process and implementation of potential activities. A comprehensive term of reference in line to the extension functions is a missing link for implementation of result oriented activities.
- The overall linkage and coordination mechanism with allied agencies is imperceptible and shady often leading to uncertainty and languid response.
- The fund allocation for implementation of extension service is insignificant in comparison to the mandates and the activities diversity.
- One extension officer one Gewog policy for wider coverage has been an old systemic approach and not suitable for potential OGTP commodity based extension interventions.
- The extension service lacks focal agency to backstop and maneuver extension service at the National perspective, and assist extension officers in planning effective coordination and reporting mechanisms.

The present extension system in Bhutan faces challenge to address technological requirements of small farmers that are consistent with their farming systems. The technological innovations are seldom in practice by the resource-poor farmers as the present innovations depend largely on the use of costly inputs which generally favor large and commercial farmers.The extension services delivery aims to poverty reduction often constrained by low and uncertain rainfall, poor soil fertility, pests' diseases, steep slopes, small irrigation, poor farm roads and other limitations. An experience is that newly generated technology may not always be relevant to the needs of poor farmers.

Extension Policy Environment

The National Extension Policy, 1995 provided direction for implementation of extension activities and served its purpose in accordance to the need of the past. The challenges and the aspiration prescribed within the overall FYP policy prompted systematic changes in the extension system. It was inevitable therefore to amend the National Extension Policy to suit address emerging challenges and ever increasing aspirations of the rural population. The private and commercial organizations like financial institutions, companies, traders, non government organizations (NGOs) functions at different strata in the rural set up but there is no appropriate policy environment that supports convergence with the existing extension system. These functionaries could be pulled in to the selected extension and production activities and secure support symbiotically in the overall rural agriculture development.

The Tarayana Foundation, one of the NGOs in the country is affianced to address poverty and sustain disadvantaged section of the communities through potential activities through various forms of support. The strategy towards agricultural growth is favored through bilateral, multilateral and international donors for agricultural development. However, the projects goals are not harmonized with FYP, on the contrary it is the FYP tuned to the project goals and objectives, and the activity ceases to continue once the project is completed. For sustainability and growth of agriculture development, the policy objective should therefore gradually move towards cost sharing and privatization trends for commercial productions, with augmented subsidized services targeting national priorities, and the underprivileged communities. The extension system in the country should facilitate to revitalize small scale farming to realize economics of scale with stronger functional links at policy formulation. The extension service with agriculture marketing should orient to help farmers to relate new market opportunities more effectively, and the arrangements should be made to provide incentives to the extension officers through profit sharing with farmers. To avoid duplication of efforts and more judicious use of resources, a functional connectivity with the NGOs and the donors should be provisioned in the policy framework. The policy should also be looked in terms of crop damages and compensation schemes through crop insurance in keeping with rural employment opportunity.

Important aspects on the policy environments are highlighted in the areas of structural adjustment as below.

- An establishment of a National Extension Forum Networking (NEFN) supports to streamline sharing of information and communication on emerging extension methodologies and technologies.

- A policy instrument to support vocational and technical institutes by public and private for the extension officers and the farmers promote farming professions for the educated youth farmers and school dropouts. A backstopping and support provisions should be packaged.

- The strategic characterization of poverty and underprivileged sections should be developed in the form of Gewog profile. The extension service to be more resource efficient and result oriented the existing research-extension functional linkage should be strengthened through partnership on technology innovations.

- The Farmers-to-Farmers Extension approach aimed to create a pool of local extension volunteers through modified Farmers Field Schools (FFS) as one of the extension tools. The local extension volunteers should be encouraged by supporting proposals of model farms and technology showcase.

- A focus extension service supported with appropriate guideline on inputs, tools and market opportunities should be reinvented.

- Support to promote One Stop Farmers' Shop model at each strategic location with active involvement of the Gewogs Extension Officers.

The policy framework should be aligned to the decentralization process and derived from the experience gained, the current gaps between the broad policy prescription and reality of deploying extension methodologies down in to implementation. The stakeholders should have the skills to analyze the systems, diagnose system failure and design remedial measures. The policy instruments such as decentralization and new concept on extension approach need to intensify capacity development.

Extension information and coordination

The RNR extension service in 2003 was reinstated with the respective parent department leaving the research services alone with the CoRRB, the then DRDS. The other allied and essential service providers such as DSC, FCB, and AMS remained split functionaries within the MOA. The decentralized extension wing functioned very much in the same way since the reorganization did not have direct serviceable influence in the field. The GYT plays important development function wherein the role of the extension officers in the motion is ambiguous resulting lowest priority on extension program. The notable hindrance to the extension service is lack of appropriate information flow and linkage mechanisms with inadequate resource allocation tied with an ambivalent reference point at the national level. The extension in the system faces varied constraints such as insufficient funds, limited number of subject matter personnel, limited training opportunities, and restricted promotion procedure. The extension service recognizes importance of professionalism but the nature of extension tasks with varied responsibility of the extension officers lead to dilution of subject matter that warrant specific skills and knowledge. The challenge of the extension service is also the complexity of production ecology with broad range technologies appealing low degrees of participation by small farmers. The extension service on using information and learning from experience for better planning of extension approaches through information sharing, activities reviews and assessment have always been at the rear.

A more micro level forum to mainstream the field based extension officers and the field activities motivate for better extension service. The realignment of ICT machinery will provide support at village set up for micro level planning, implementation and evaluation making informed decision mobilizing farmers into different interest groups. The convergence of information flow both ways should be further supported and strengthened for effective planning and reporting process. A system of demand driven based on technical suitability with accessibility of communication technology will enhance capacity of the rural population in decision making process. The rural agriculture development and extension education should be matched with achievable targets and resources with appropriate short, medium and long term plans for implementation, besides an effective communication links between

researchers and extensionists are vital in technological recommendations and research that suits most in the subsistence farming.

The institutional adjustment and improvement of coordination mechanism shall be realized through systematic adjustments as follows:

- The resources allocation linking to priority activities with proper field analysis and technology options should be realigned and connected in the context of extension activities.

- The extension coordination, monitoring and back up service should be established at each Research and Development Centers (RDCs) with appropriate mandates.

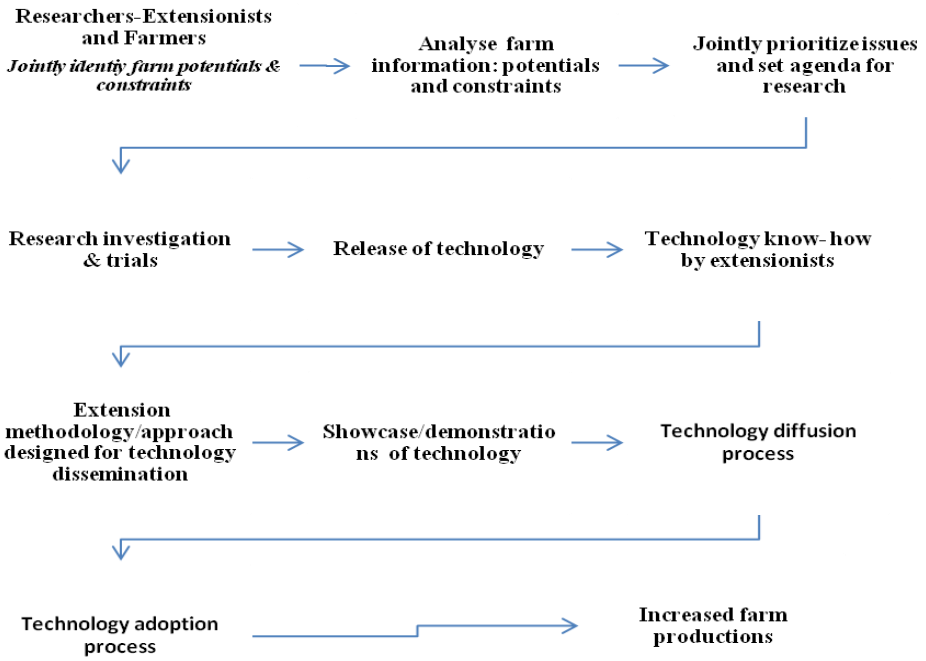
- The Information communication for extension service should be associated directly with technology generation and dissemination and further prioritized on extension methodology development, gap identification, planning and implementation.

- The extension service should have its own HRD plan for carrier development and staffing set up in view of its coverage and the mandates.

The extension service should continue to update to be able to the "Cyber extension" for fast and effective sharing of information, technologies, diffusion and adoption at the farms and within the allied agencies.

Technology Generation

Farm technologies adoption rate depend on how friendly the technology is in terms of applicability, cost and pragmatic to the farmer that his families do not go famished if the technology fails to generate desirable outputs. Therefore, it is of paramount importance to generate farm technology which is realistic, resilience and cost effective. A critical analysis prior to research should be indivisible involving relevant stakeholders in the system. The adoption of any farm technology depends on how well the technology is blended within the local context and beliefs. A critical analysis prior to research shall be inseparable involving relevant stakeholders in the system. Figure 1 represents a diagrammatic representation on the progression of appropriate farm technologies.


Researchers-Extensionists and Farmers
Jointly identify farm potentials & constraints
Analyse farm information: potentials and constraints
Jointly prioritize issues and set agenda for research
Research investigation & trials
Release of technology
Technology know-how by extensionists
Extension methodology/approach designed for technology dissemination
Showcase/demonstrations of technology
Technology diffusion process
Technology adoption process
Increased farm productions

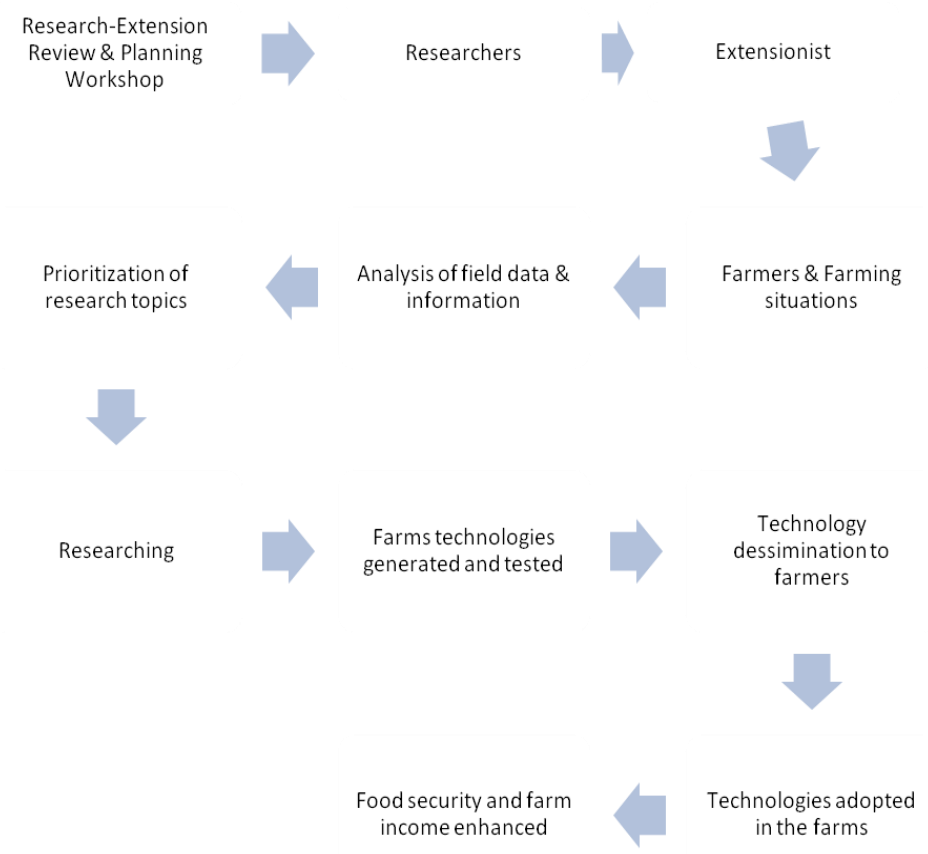


Figure 5: Simple process for development of a potential technology for farming communities

Extension support mechanisms

The Department of Agriculture since 2003 made a leap towards focus commodity based development. The challenge to the progression of the commodity based development was a shift of extension service from a blanket approach to a more technical and professional based extension service.
This shift warranted the extension officers to understand technical parameters of each priority commodity under production and diversification following "Triple Gems Concept". The parameter was to weigh commodities more technically with potentials based on agro-ecology, soils, water, rural access and markets that demand analysis of agro-ecology and market opportunity for planning and design appropriate technical interventions for commodity development. This concept is yet to be formalised at the implementation level due to want of better understanding and capacity among different actors.

The 9th FYP lacked implementation strategies for commodity development as a result the extension service delivery to the rural communities quietly suffered. The extension approaches therefore, by and large remained unchanged despite change prescribed in the plan document. The limited capacity of the extension officers in planning and implementation of commodity development concept vis a vis a limited resource allocation bottlenecked implementation. The support services catered by extension co-actors have been in piece meal without defined mechanism. Besides, the extension service being a decentralized wing that the role of the Department has been limited to coordination, facilitation, HRD and policy related matters. The technical support to extension at the planning and implementation lacks a distinct connectivity. The support mechanism should be strengthened to focus more on planning, budgeting, and implementation of the extension programs

The research and extension linkage should be further strengthened not just for technologies but interactive relationships between institutions and communities should be perceived as central to the goal of enhancing people's participation. The key indicators for reporting agricultural activities need to be identified with introduction of unified formats for effective reporting besides; the elements like community-based

organizations and Self Help Groups (SHGs) should be supported to play significant role in agriculture development.

Contextual extension approaches

The use of any extension approach that suit best at a given time and space must be well thought and assessed in terms of social, ecological and material resources. Any extension tool or approach when determined to apply for a certain cause must be weighted in terms of gaining confidence of the local people with assertion of behavioral changes and their active participation. The selection of a right extension approach shall persuade farmers themselves trying out innovations and adoption of the proven technology for their betterment.

The extension approaches are very many but their relevance in a given situations should be assessed before application. The records and references indicate that there is no any single extension approach that is superlative in the rural livelihood improvement process, but the users' experience and knowledge with support of the communities will help to design or select the most appropriate ones. The extension approach being applied in a given time and space firmly depends on the purpose, situations and the target group. The Training & Visit (T&V) was one of the most popular extension approaches that suited well for agricultural development through informal education and training system during 1960s but was later discarded being expensive and stereotype.

Therefore, there is no suitable common extension approach for multi-purpose use at all rural settings. As for Bhutan, the Commodity Extension Approach (CEA) has been conceptualized in 2003 taking in to consideration the diversity of farming systems, social and agro-ecological potentials: a technical based extension focuses to potential activities for intervention. The CEA has not been quite popular in the present state due to want of appropriate location specific information on potentials and constraints and inadequate funds for extension activities. The CEA being hybrid and derivatives approach from the seven extension approaches listed in circular Fig. 2 which shall be the way forward for effectual extension service to our farming communities.

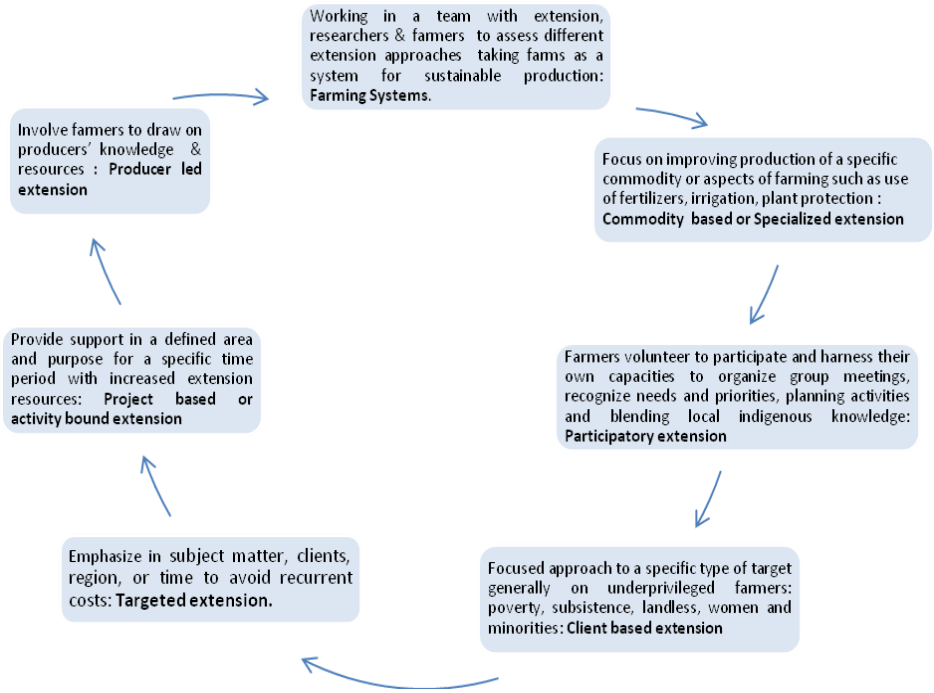


Figure 2: An analysis of different extension approaches: The CEA model

Status of extension service

The extension service demand has always been high from farmers, Government agencies and the NGOs. Some significant areas of extension service are transfer of technologies, information on land, crops, varieties and production, diversity, soil fertility, land capability, soil analysis, resettlement & land identification, pests/diseases information, damage assessment, irrigation, farm road, surveys, food security assessment, demographic information, post harvest, mechanization, marketing, land conversion and land management & farmers group formation. The Extension bearers need to engage with a wide range of issues beyond disseminating technologies which has raised the need for better-qualified and specialized extension officers to meet the technical demands. The capacity of the extension officers should be strengthened on the subject matter for service delivery that entails an essential condition for steering,

organizing, and accelerating agriculture development process more professionally. The extension scenario indicates that a stratum of different understanding levels among the extension officers in terms of capacity and motivation suggest that they desire motivation and capacity in extension subject matter. The accountability of technology transfer and adoption of innovation do not match to the knowledge and skills.

The extension officers having specific training and skills when not placed in the right type of jobs leads to dilution of very essence of professionalism, similarly the effective service delivery is hampered due to lack of enabling supports to carry out the entrusted roles and responsibilities. The profession of the extension officers in the local governments should be made explicit with definite role play in the Gewogs forums. The extension officers are most often engaged for non technical and non extension jobs while their accountability is predetermined in the event of failure of the program. A high degree of administrative task prevailed at the Gewogs in realizing the mandated technical extension responsibilities.

The existing band of field officers (Certificate holders, NATI Diploma, CNR Diploma in to two categories: class X + 3 years and class XII + 2 years) often confuse themselves in the delivery of extension service due to different levels of exposures, education, age and experiences. The assignments should match the knowledge and skills with better exposures to social aspects, extension methodologies, coordination, and approaches. The technologies on demand by extension and farmers continued to remain low, while the available farm technologies have either become obsolete due to delay in reaching to the extension or have been inappropriate because of complexity and high cost. Thus the innovations do not seem to provide attractive outputs in terms of production and cash income generation to the farmers. There is a lack of desired facilities and extension strategy at the implementation level limiting appropriate method for technology dissemination and tantalizing adoption process.

The other issues arising due to weak capacity and multitasking of extension officers are:

- Poor response on technology adoption is due to lack of confidence of the extension officers on extension methodology together with uncertainty on market demand of surplus produce, outbreak of pests-diseases, wild animals damages, irresolute environment with composite and expensive farm technology.

- The on-going efforts on know-how and exposures of the farmers in farming technology remained with minimal impacts. The methodologies in farmers' trainings and farmers study tours do not seem good contributor in terms of capacity, technology adoption and self oriented initiatives by the beneficiaries.

- An effective synchronized participatory farmers implementation plan based on priority commodity against each production environment should be realized

- The impact of technology park development seems not working towards sustainability; the methods, process and support need to be readdressed.

- The roles of extension officers in Water Users' Association (WUA) and Farm Road construction should be reassessed and trainings arranged.

- The office facilities available in the present context vary both at the Dzongkhags and Gewogs: project supported Dzongkhags and Gewogs receive better facilities and training.

- The printed extension materials hardly reach the field staff on time, there is no model in place for production and distribution of extension materials. The training material such as charts, pamphlets, pictures, motion pictures, white boards for farmers' trainings are rarely on demand from the extension officers.

- The use of mass media such as radio and TV is yet to become essential part in our context for information sharing in extension service.

The extension should take up increasingly the role of enabler and needs to have a wide range of competencies to perform new challenges. The extension officers need an increasing level of social science skills related to group formation, leadership development, conflict resolution, and inter-group negotiation. The motivation for improved job satisfaction is an indispensable aspect of good management and is a pro-active human resources strategy that could lead to a vibrant rural economy.

Reflections

A general Extension Service does not seem to address the need and the aspiration of the farming community in the globalised context of market economy and professionalism. The participatory commodity extension approach shall provide impetus in addressing current field issues focus to commodity development to achieve tangible field impacts. The extension system so adjusted and realigned in line to the techno-socio extension service is projected to initiate further assessment and analysis of production environment in accordance to the farming systems and the social structure in place.

The lessons learnt from the past direct the extension service to focus on priority commodities at each agro-ecological cluster keeping in the OGTP concept. Further, the experience shows that a focal point to lead national extension program should be institutionalized to identify extension environment, scope of commercialization and efficacy assessment of extension service. The transformation of extension demands into field reality with political commitment and that the lessons from recent and ongoing extension service should be applied to design future reform measures to avoid repeating the known negative experiences. The extension services intending to develop more technical base pool of farmers should adopt a more liberal participatory Farmers Fields Schools model with necessary adjustment at own needs.

As practiced in China, working through and constitution of farmers association to take up various production, marketing and extension functions could be initiated. The private sectors and NGOs role in contract farming approach should be attempted and introduced in our extension system for commercialization venture. The farmers growing crops under contract is gaining popularity in India by private companies. The present initiatives of the department have been production focused based on potentials matching to market opportunity and accessibility. The extension activities therefore should be interlinked directly to the rural access program to augment people's participation and to enhance food security and income generation.

Way forward

The extension dimensions to ensure better livelihood for the rural people through enhanced extension service desire few addendum and synchronization as the way forward that follows:

- There is a need to link commodity programs and the OGTP towards technical potentials, matching national and local development plans with suitable extension approaches and methodologies supported by the RDCs

- All functional Gewogs should be supported to develop agriculture profile of each potential site with an area specific plan for implementation. The extension frontline officers should be trained to comprehend situational analysis

- The promptness of field visit and frequency of feedback by the officials from the department and the central programs should be systematized. The research and development centers, divisions and central programs should realign their roles to address field issues with appropriate linkage mechanism taking farm economics as a part of the technology package.

- The staffing capacity, positioning, deployment and facilities should be assessed including provision of mobility in coordination with ECC. The provision of proper offices, residents, extension equipments and reference papers should be standardized

- The one Gewog one extension officer policy should be justified in terms of potentials, demand, size and population. The rationalized placements of extension officers at the Gewogs with less agriculture potentials should be pooled to be attended by maximum of two while large and potential Gewogs by two extension officers. The potential Dungkhag should be placed with one extension officer each to backstop report & monitor the field activities

- The database of agriculture personnel should be further streamlined to facilitate better coordination and designing need based training opportunities. The guideline on staff transfer should be enforced towards guarantying equity, transparency and safeguarding innovative extension officers.

- There is a need to develop a guideline on training opportunity for the extension officers and other professionals in the system. The opportunity for promotion & up-gradation should be linked to work performance and initiative.

- Rewards and penalty system should be strengthened with clear line of assessment at each functional stratum with appropriate guidelines. The opportunity shall be measured with field outputs and impacts and on the initiatives of the field staff creating difference in the lives of the rural people.

- Bhutanese extension system will be functionally distinctive only when farmers to farmers' extension with technically sound farmers are active. The One stop farmers shop design to provide market opportunities for supporting small farmers to sale their small surpluses and provision of value additions of products

- There is a need to review and develop appropriate extension user's manuals and guideline as appropriate as field implementation guide and/or record keeping

- The present Information Management Section should be upgraded to an Extension and Information Division (EID) to give more focus on the extension service, besides support to information management and M&E.

- Rehabilitation of staff requiring special attention and support should be initiated to reduce dispiriting situations and precedence.

To make a lasting positive change in people's lives and on how people perceive themselves requires extension officers that are more competent and compassionate collectively with appropriate line of functions and favorable policy guideline in place.

The Fig 3 represents a functional and coordination mechanism a way forward aftermath of 2009 reorganization.

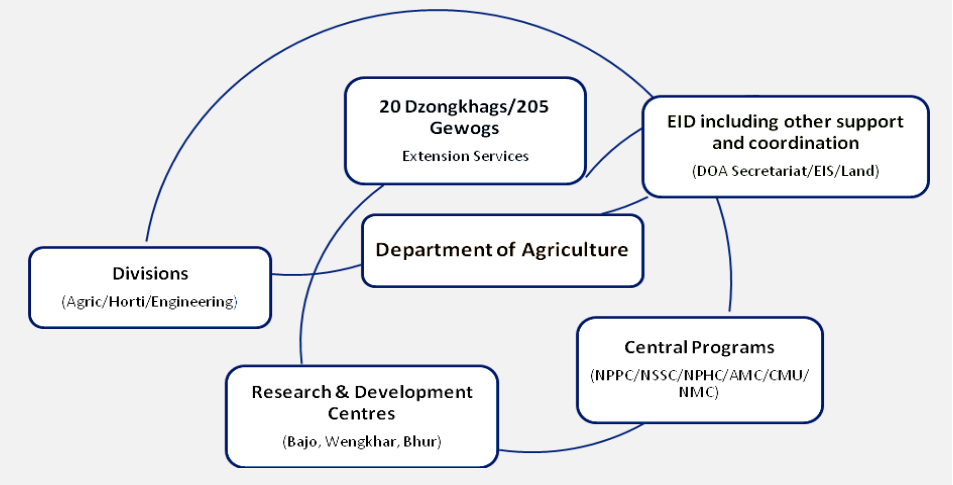


Figure 3: Functional & Coordination mechanism aftermath of recent reorganization

CONCLUSION

The extension service of the Department of Agriculture will continue to cater towards fortifying livelihoods of the farming communities through design and application of appropriate extension tools and approaches. The extension service will continue to further to fine-tune in addressing changing demand and aspirations of the people and demand of the government by uniting stakeholders closer to achieve common goals for food security and rural income generation besides employment opportunities. The extension service is for, and of the rural people that cater from their courtyard to farms and facilitate to their need, want and

wish. Therefore, the potency of the extension service in the Bhutanese context to bring change in the life of our rural people cannot be compromised for years to come.

The small farmers with feeble bargaining powers and limited political voice make extension service delivery multifaceted. The extension system with researchers needs to address technological requirements of small scale farmers that are consistent with their farming systems. The current innovations are rarely adopted by the resource-poor farmers demanding costly inputs and bearing of unintended threat to their very survival. The available technologies favors large commercial based farmers who can afford to take risk as they have an alternative source of income. The technology transfer by extension in isolation will not solve the problems, both technological innovations and sociological change must be stimulated simultaneously to explore voluntary participation of all players involved to bring about positive sustainable change. The ICT in the extension with greater involvement of related agencies surely boost livelihood through the extension service. The extension managers, policy makers and the communities should join more professionally to discover viable options for providing a better and packaged extension services to meet emerging challenges in the rural Bhutan.

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